The response of the vegetation to a range of alternatives to clearfelling of tall wet eucalypt forests at the Warra silvicultural systems trial, Tasmania, Australia.

by

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requirements for the degree of Doctor of Philosophy

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Declaration

I hereby declare that this thesis contains no material which has been accepted for a degree or diploma by the University or any other institution, except by way of background information and duly acknowledged in the thesis, and to the best of the my knowledge and belief no material previously published or written by another person except where due acknowledgement is made in the text of the thesis, nor does the thesis contain any material that infringes copyright.

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Abstract

Clearfelling of wet eucalypt forest followed by high intensity burning and aerial sowing, a silvicultural system used for the last 50 years in Tasmania and designed to mimic the natural dynamic of sporadic regeneration following cataclysmic disturbance, has attracted criticism for not maintaining the structural or floristic diversity that is associated with natural disturbance. To address these concerns, a silvicultural systems trial was established at the Warra Long-Term Ecological Research site in southern Tasmania to quantify the effect on these values if variable-retention harvesting systems are applied to tall wet eucalypt forest. The harvesting treatments were clearfell, burn and sow with understorey islands, a patchfell, stripfell, dispersed retention, aggregated retention, single-tree/small-group selection and group selection. High intensity burning, low intensity burning and no burning were variously applied as part of these treatments. Stocking, density and growth of the eucalypt seedling regeneration, floristic changes and the structural integrity of retained forest areas were monitored for up to ten years after harvesting and regeneration treatments were applied from 1998 to 2007.

The nature of the seedbed in each coupe was related to the harvesting and regeneration treatment. Where high intensity burns were applied there was a higher proportion of burnt seedbed available than in coupes where low intensity burns were applied. The highest eucalypt seedling densities and fastest early growth rates occurred on the hottest burnt seedbeds. The lowest seedling densities occurred on unburnt and undisturbed seedbeds and the slowest early growth rates occurred on unburnt and compacted seedbeds. Treatments that created the most burnt seedbed had the highest eucalypt seedling densities and mean seedling growth rates.

The floristic response in any given coupe following the harvesting and burning disturbance was related to the pre-harvesting floristics and not to the silvicultural system. Rainforest species present in the understorey prior to harvesting were also present in the post-harvesting vegetation, albeit at lower levels. Sclerophyll dominated understoreys regenerated with a very similar species composition to that pre-harvesting. Damage to the edges of retained forest areas was minimal, except for the smallest

areas, which were prone to windthrow and were often burnt during the regeneration burn. Larger areas persisted intact throughout the harvesting and burning operations and for the first few years after those disturbances.

Of the silvicultural systems examined in this study, aggregated retention is considered the most promising alternative to clearfelling. High intensity burns as applied to clearfell burn and sow coupes cannot be conducted in aggregated retention coupes as they would probably burn the aggregates. The lower proportion of burnt seedbed resulting will, on average, lead to lower seedling density and growth rates, and may compromise longer term productivity compared to clearfelled and high-intensity-burnt coupes. If aggregated retention is to be successfully applied, as measured by the density and height growth of the regeneration, finding ways of successfully and consistently burning such coupes post-harvesting will be essential.

Keywords: Australia, *Eucalyptus obliqua*, regeneration, silvicultural systems, variable retention, seedbed.

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Related papers:

Hickey, J, Neyland, M. G. and Bassett, O. (2001). Rationale and design for the Warra Silvicultural Systems Trial in wet *Eucalyptus obliqua* forests in Tasmania. *Tasforests* 13, 155-182.

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Poster papers

Hickey, J., Neyland, M., Edwards, L. Marsden-Smedley, J. and Plumpton, B. (1998). Testing alternative silvicultural systems for wet eucalypt forests in Tasmania. Some operational considerations of overstorey retention treatments. Poster paper presented to the IUFRO conference, August 1998, Melbourne.

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Conference presentations

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Neyland, M.G. (2004). Seedling regeneration, growth and density of *Eucalyptus obliqua* following partial harvesting in the Warra silvicultural systems trial. 3. The first “clearfell, burn and sow” coupe, Warra 8B, age 3 years. Technical Report No. 142, Cooperative Research Centre for Sustainable Production Forestry and Forestry Tasmania, Hobart.

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Neyland, M.G. (2004). Seedling regeneration, growth and density of *Eucalyptus obliqua* following partial harvesting in the Warra silvicultural systems trial. 6. The first “single tree/small group selection” coupe, Warra 5D, age 3 years. Technical Report No. 149, Cooperative Research Centre for Sustainable Production Forestry and Forestry Tasmania, Hobart.

Contents

Chapter 1. Introduction

Tall wet eucalypt forests in Tasmania are characterised by trees > 34 m tall forming an open forest canopy over a dense secondary layer of small trees and tall shrubs (Wells and Hickey 1999). Where the secondary layer is dominated by rainforest species, the forest is termed mixed forest (Gilbert 1959). Where the secondary layer is dominated by any of a variety of broad-leaved shrubs it is termed wet sclerophyll forest. The term wet eucalypt forest is used to encompass both mixed forest and wet sclerophyll forest (Kirkpatrick *et al.* 1988). Wet eucalypt forests have been an important source of timber in Tasmania for more than 200 years (Elliott *et al.* 2008). How these forests are managed, both for timber production and nature conservation, has been the subject of intense public debate for decades (e.g. Dargavel 1995; Public Land Use Commission 1996).

The low levels of light under the dense secondary layer and the deep litter layer mean that in the absence of significant disturbance, the overstorey eucalypts cannot regenerate (Attiwill 1994). In natural conditions, eucalypts in wet forests only regenerate following infrequent but usually intense wildfires that consume the abundant leaf litter and much of the understorey, thus presenting the shade intolerant eucalypt seedlings with receptive seedbed and high light conditions for early rapid growth (Gilbert 1959; Cunningham 1960a; Ashton 1981b; Attiwill 1994). Gilbert (1959) noted that the important conditions for seedling establishment created by the wildfire included the removal of the dense understorey with a resultant dramatic increase in forest floor light intensities, the removal of the litter layer, exposure of the mineral soil, high nutrient availability from the ash, heavy seedfall from the large numbers of capsules which survive on parent trees, reduction in the numbers of insects which harvest seed, and good rains associated with cold fronts which often follow extreme fire weather.

Clearfelling followed by high intensity burning and aerial sowing of seed collected from the harvested area or locally, has been the dominant silvicultural system for tall wet eucalypt forests in south-eastern Australia since the 1960s (Hickey and Wilkinson 1999a). The adoption of this system followed the elucidation of wet eucalypt forest ecology by Gilbert (1959) and Cunningham (1960). Clearfelling is defined as the felling of all or nearly all the trees on an area (a coupe) in a single operation, where the minimum size of the coupe has a diameter of more than four times the average tree height (Smith *et al.* 1997; Forest Practices Board 2000). Coupes in Tasmania average about 50 ha (Forestry Tasmania 2007b). The harvest residues are burnt in a high-intensity burn lit under rigidly prescribed conditions in autumn (Forestry Tasmania 2005), and the coupe is then aerially sown with seed, from on-site or local sources, that reflects the original species composition on the site (Forestry Tasmania 2007a). The clearfell, burn and sow (CBS) system is used because it is considered relatively safe for forest workers (Mitchell 1993), gives the highest financial return to the forest owner (Nyvold *et al.* 2005), and the slash burning maximises seedbed, encourages eucalypt establishment and growth, and removes fuel that would pose a subsequent fire risk (Forestry Tasmania 1998). Planned rotations are about 90 years (Whiteley 1999).

To some extent the CBS system mimics the natural wildfire system (Attiwill 1994; Hickey 1994), particularly as the wildfires expose the soil and trigger the release of canopy-stored seed, however critics of CBS have noted some significant differences. Wildfires typically are not stand replacing, many trees survive wildfires, and much of south-eastern Australia's wet forests are multi-aged (Lindenmayer *et al.* 2000; Turner *et al.* 2008). Conversely, regeneration arising from CBS is even-aged. The natural disturbance regime creates more complex landscape patterns (Lindenmayer *et al.* 1999) and leaves a greater local structural diversity (Lindenmayer and McCarthy 2002). Repeated CBS rotations of around 90 years are likely to lead to a decline in the abundance of late successional species and structures (Hickey 1994; Lindenmayer and McCarthy 2002), and ultimately to a possible decline in the timber resource based on the rainforest species. Clearfell burn and sow operations are also aesthetically displeasing, particularly in the first two or three years after the burn, until such time as the area has regenerated.

Whilst the timber harvesting industry recognised that clearfelling was a safe, effective and efficient method of harvesting tall wet eucalypt forests from a wood production perspective (Smith *et al.* 1997), social attitudes to clearfelling through the 1980s and 1990s were negative and it was clear to most observers that some changes were required. The Tasmanian Regional Forest Agreement (Commonwealth of Australia and State of Tasmania 1997) recognised this and noted a priority for research on 'commercial viability of new and alternative techniques especially for harvesting and regenerating wet eucalypt forests and maximising special species timbers and rainforest regeneration where appropriate'. The changes happening in the Tasmanian political and social milieu at that time were not unique but had parallels in many other parts of the world. Trials to develop more ecologically-based silviculture for cool temperate and boreal forests, whilst maintaining safe workplaces for the harvesters, were under development in other parts of Australia (Squire 1990), the Pacific Northwest (Franklin *et al.* 1997; Aubry *et al.* 1999; Franklin *et al.* 1999), Canada (Scientific Panel for Sustainable Forest Practices in Clayoquot Sound 1995; Arnott and Beese 1997; Mitchell and Beese 2002), South America (Vergara and Schlatter 2006; Martinez Pastur *et al.* 2007) and Europe (Fries *et al.* 1997).

The Warra silvicultural systems trial (SST) was established from 1998 to 2007 to compare alternatives to the traditional CBS harvesting method for tall wet eucalypt forests (Hickey *et al.* 2001). The trial was located on an area of relatively uniform slope (predominantly 5 to 12°), aspect (southerly) and soil type. Quaternary dolerite talus overlies Permian sediments in all the coupes except one, (Warra 1A, see Figure 2.1), in which the Permian sediments are much more exposed. Aerial photo interpretation of the vegetation (Stone 1998) indicated that before the SST was established the vegetation of the area was relatively homogeneous, except along major drainage lines where rainforest elements were more obvious beneath the ubiquitous eucalypt canopy. Six treatments were applied in the trial. The systems, the rationale for the different systems, their perceived advantages and disadvantages, and the establishment of each of the coupes in the trial are described in the following chapter. To assist readers, a labelled map of the trial at the completion of harvesting and burning, is in a pocket on the inside back cover of this thesis.

The SST is located in the Warra long-term ecological research (LTER) site (Brown *et al.* 2001) in multi-aged (Alcorn *et al.* 2001), 50-m tall, lowland wet *Eucalyptus obliqua* forest (species nomenclature throughout follows Buchanan (2005)). Wet *E. obliqua* forest is the most widespread and abundant commercial native forest type in Tasmania, occupying some 425 700 ha (Public Land Use Commission 1996). The forests at Warra are representative of many of the tall *E. obliqua* forests in Tasmania, particularly of those in southern and south-eastern Tasmania but also, with some qualification, of *E. obliqua* forests elsewhere in the State (Neyland *et al.* (2000). Hence the findings from the Warra SST may inform management of tall *E. obliqua* forest elsewhere in Tasmania.

Initial treatment selection was guided by trials of silvicultural systems that had previously been established in wet eucalypt forests in Tasmania (Neyland *et al.* 1999; Bassett *et al.* 2000) and south-eastern Australia (Squire 1990). As establishment progressed, developments in the Pacific Northwest in particular (Arnott and Beese 1997; Franklin *et al.* 1997; Mitchell and Beese 2002) led to the addition to the trial of the aggregated retention treatments, and adoption of the variable retention terminology, which encompasses dispersed, aggregated and mixed (a combination of both dispersed and aggregated) retention systems (Mitchell and Beese 2002).

The first major evaluation of the trial was planned for when all the treatments had reached at least three years of age, which was expected to be in 2005, the coupes having been established between 1998 to 2002. As explained in Chapter 2, establishment of the trial was ultimately completed in 2007, so it will be 2010 before all treatments are at least three years of age. Preliminary evaluations of the treatments have been necessary in order to make operational decisions (Hickey *et al.* 2006). Evaluation of the trial encompasses four main criteria: social, economic, ecological and silvicultural (Hickey *et al.* 2006). The focus of this study is on the ecological and silvicultural outcomes of the treatments. The central hypothesis is that the vegetation, both the overstorey eucalypts and the understorey, varies in response to the different silvicultural systems being applied.

Successfully established and adequate *Eucalyptus* spp. regeneration has long been recognised as part of sustainable forest management in Australia (Lutze *et al.* 2004). The Australian Forestry Standard through Criterion 4 'Forest management shall maintain the productive capacity of forests' and more specifically under requirement 4.4.4 'The forest manager shall ensure that regeneration of native forests [and establishment of plantations] is effective and timely', has recognised the central importance of regeneration success (Standards Australia 2003). The quantity and quality of the regeneration in the alternative treatments being examined at the Warra SST, as compared to CBS, is therefore a key measure of their success. Successful regeneration is dependent on the creation of suitable seedbed, and an adequate supply of seed (Florence 1996).

Following harvesting in wet eucalypt forests some form of site preparation is essential to prepare seedbed that is receptive to eucalypt seed (Ashton 1981a; Attiwill 1994). The site preparation is required to remove the large amounts of debris that are created during harvesting of wet eucalypt forests (Marsden-Smedley and Slijepcevic 2001). The traditional approach to removing the debris is a high intensity fire. High intensity fire is the most economical and effective method, and it has less physical impact on the soil than mechanical site preparation methods (King 1991).

Successful high intensity burns, that remove the majority of the harvesting debris and that do not extend beyond the planned extent, require good planning, roughly circular coupe shapes, or at least coupe boundaries with no jagged peninsulas, and a strong fuel moisture differential between the coupe and the surrounding forest (Forestry Tasmania 2005). Initial central lighting creates a strong chimney effect such that subsequent edge lighting is drawn towards the centre of the coupe, minimising the risk of the fire escaping. The fires are very intense for a short period, and most of the fine fuels (less than 10 mm diameter) are consumed. The coupes tend to smoulder only for a day or two as there is little available unburnt fuel.

In planning the alternatives to clearfelling being examined within this trial it was recognised from the outset that high intensity fires could not be applied to some of the alternatives, such as the dispersed retention system, without deleterious effects on the retained trees, and that the coupe shape and sizes of other systems, such as the stripfells, meant that high intensity burns probably could not be achieved. Finding ways of successfully creating sufficient receptive seedbed was therefore an important part of the Warra SST, and as the trial developed operational trials of alternative burning methods were also underway (Chuter 2007).

There are also other measures of the success of the alternative treatments. The regenerating stand in the first 20-30 years following CBS treatments has been shown to be floristically distinct from that of forests recovering post-wildfires (Hickey 1994), in that there was a lower abundance of epiphytic ferns (late successional species) and a higher incidence of a common sedge species (an early successional species) in the silvicultural regeneration compared to the post-wildfire regeneration. As many of the alternative treatments being explored within the Warra SST retain some elements of the original stand after completion of the harvesting and regeneration processes, it is a reasonable hypothesis that the post-disturbance stand will retain more in the way of late successional species and/or that they will recover more quickly than in post-CBS stands, as there are greater opportunities for spore and seed dispersal out from the retained forest and into the silvicultural regeneration. As noted above, the Regional Forest Agreement process recorded a particular interest in the regeneration of rainforest species (myrtle, sassafras, celery-top pine, leatherwood and blackwood (*sensu* Jarman *et al.* 1984)), as these provide not only particular habitat types but are also an important source of timber, particularly for the fine furniture and craftwood industries. The five rainforest species are commonly referred to together as special species.

Summary and major objectives

This thesis has eight chapters. Establishment of the trial is described in Chapter 2. The five research chapters (chapters 3 to 7) describe the pre-harvesting vegetation and examine the response of the vegetation, both understorey and overstorey, to the different treatments. Chapter 8 discusses the results of the research and its implications for current and future forest management. The objectives of each chapter are summarised below.

Chapter 2 describes the process of establishing each of the coupes within the trial. Each coupe presented different issues, and provided particular learning experiences, and these are discussed. The objectives, and perceived advantages and disadvantages of each of the treatments are described.

Chapter 3 presents a description and analysis of the pre-harvesting vegetation of the trial. The objective of this work was to characterise the nature of the vegetation of the Warra silvicultural systems trial prior to the establishment of any treatments, in order to provide a basis for both short- and long-term studies of the responses of the vegetation to the range of treatments.

This chapter has been published in a slightly different form in Tasforests 13 (2) 183-192.

Chapter 4 examines the short-term (up to six years) post-harvesting response of the vegetation. The hypothesis was that the response of the vegetation would vary in response to the intensity of the harvesting and burning disturbances associated with each silvicultural system.

In Chapter 5 the short-term (again, up to six years) post-harvesting response of the understorey islands is examined. A subset of the larger floristic response study, the understorey islands were established particularly to examine the recovery of understorey species that primarily rely on vegetative recovery for their persistence. The hypothesis was that retention of understorey islands would increase the post-harvest floristic and structural diversity within the harvested coupe.

Chapter 6 examines the extent and persistence of the structural retention within the aggregated retention and stripfell/patchfell treatments in the trial. Improved structural diversity within regenerating stands is considered to be one of the three key attributes of successful variable retention harvesting (Franklin *et al.* 1997). The hypothesis was that retention of unharvested forest, as strips or aggregates, within the harvest boundary would increase the post-harvest structural diversity within the harvested coupe.

Chapter 7 examines the response of the eucalypt regeneration to the different treatments. The hypothesis was that the eucalypt regeneration would be favoured by larger openings and regeneration burns of higher intensity.

This chapter has been published in a slightly different form in Forest Ecology and Management 258, 481-494. It reproduces some background information from other parts of this thesis.

Chapter 8 brings this research together and discusses the implications of the research for current and future management, in the light of developments in similar research into alternatives to clearfelling in temperate forests that are currently being undertaken across the globe and makes recommendations for new areas of investigation.

Chapter 2. Establishment of the Warra silvicultural systems trial, 1998 to 2007.

Introduction

This chapter describes the establishment of each coupe within the Warra silvicultural systems trial (SST). The different silvicultural systems applied ('the treatments'), including their perceived advantages and disadvantages, are described (see Table 2.1). The rationale for the selection of treatments is described in Hickey *et al.* (2001)) and is discussed briefly for each treatment below. The timing of the harvesting, burning and sowing (where applied) of each coupe is shown in Table 2.2., and the final experimental layout in Figure 2.1. Aerial views of the SST prior to and after the completion of establishment are shown in Figure 2.2.

Six treatments were applied: (1) clearfell burn and sow with understorey islands (CBS-UI); 40 m by 20 m patches of understorey retained undisturbed during the harvesting, (2) 80 m wide stripfells (STR) separated by retained strips of similar width, (3) a patchfell (PAT), not replicated, established to demonstrate the natural seedfall pattern and to inform the likely maximum strip width that could be applied in stripfelling, (4) dispersed retention (DRN), wherein 10 to 15% of the original basal area was retained as evenly dispersed trees, (5) aggregated retention (ARN), wherein 30% of the coupe by area was retained in aggregates of half to one hectare, and (6) single tree/small group selection (SGS). For consistency, results from these treatments are presented in this order throughout this thesis.

When the SST was first under development (1997) it was planned that two replicates of each treatment would be established within three years, and that the results from the trial would be reported when all the treatments were at least three years of age, in 2003. As explained below, the replication was largely, but not entirely, achieved, and establishment took longer than planned. A series of stop-work meetings over safety concerns in the first dispersed retention coupe resulted in a change to the prescription as that coupe was nearly completed (see below). The first single tree/small group selection coupe was deemed to be such a dangerous operation that it should not be repeated, nor was the outcome acceptable to the design group, so the second group selection coupe (and note also the change of name), was harvested to a different prescription than the first. Different weather conditions

Table 2.1. Treatments and objectives at the Warra Silvicultural Systems Trial.[1]

Treatment	Coupe name	Harvesting objectives	Potential advantages	Potential disadvantages
Clearfell, burn and sow with understorey islands (ground-based harvesting). Clearfell coupes of approximately 20 ha with up to 5% of the coupe to be in dispersed 40 m by 20 m machinery-free areas, high intensity burn, and aerial sowing of on-site or in-zone seed. (CBS-UI).	WR8H WR8B	• Efficient and safe eucalypt harvest with close to maximum potential growth of eucalypt regeneration and enhanced local survival of understorey flora on, and potentially around, the machinery-free areas.	• safe harvesting • low supervision costs • established approach to slash burning • receptive seedbed for eucalypts • low fuel loads post-burn • fast eucalypt growth • high return to grower The understorey islands may also provide: • better survival of late-successional flora, and • a source of propagules to recolonise the coupe.	• high visual impact • few late-successional species • few special species[2] • low structural diversity • smoke • nutrient loss • the understorey islands may present a smoulder risk post burning
Patchfell (cable harvesting) 240 m by 200 m patch, high intensity burn, natural seedfall (PAT).	WR1A (F)	• Efficient and safe eucalypt harvest with maximum potential growth of eucalypt regeneration and adequate biodiversity outcomes. This coupe was harvested to aid investigations into the maximum dispersal distance for eucalypts and special species.	• As above plus this treatment will enable an estimate of the maximum recolonisable strip width applicable in stripfelling.	As above
Stripfell (cable) Openings of c. 250 m by 80 m strips, moderate intensity burn, natural seedfall (STR).	WR1A (N) WR1A (L)	• Harvest the eucalypts as safely as possible, with adequate growth of eucalypt regeneration and enhanced biodiversity outcomes, by retaining strips of unharvested forest between harvested strips of similar size.	• improved special species regeneration • natural seed supply • improved visual impact	• many more coupes required for same area harvested • more roading • more burns • windthrow within retained strips can lead to reduced production
Dispersed retention (ground). 10-15% BA retention, low intensity burn, natural seedfall (DRN).	WR1B WR8C	• Harvest the eucalypts as safely as possible, with adequate growth of eucalypt regeneration and enhanced biodiversity outcomes by retaining individual eucalypts for a full rotation.	• retention of structural diversity • more hollows for fauna • large log habitat • improved aesthetics • natural seed supply	• higher risk to harvesters • difficult fire management • reduced eucalypt seedbed • variable seed supply • potential for reduced eucalypt regeneration growth

Notes. 1. This table has been developed from Hickey *et al.* (2001) and Hickey *et al.* (2006).
2. Special species are non-eucalypt tree species which can produce fine timber; they include blackwood (*Acacia melanoxylon*), myrtle (*Nothofagus cunninghamii*), celery-top pine (*Phyllocladus aspleniifolius*), sassafras (*Atherosperma moschatum*) and leatherwood (*Eucryphia lucida*).

Table 2.1. Treatments and objectives (cont.).

Treatment	Coupe name	Harvesting objectives	Potential advantages	Potential disadvantages
Aggregated Retention (ground) 30% area retention, majority of harvest within one tree length of retained forest, retain aggregates of 0.5 to 1.0 ha, low intensity burn, natural seedfall (ARN).	WR1E WR8I	• Harvest the eucalypts as safely as possible, with adequate growth of eucalypt regeneration (and special species if present) and enhanced biodiversity outcomes by retaining patches of undisturbed forest for a full rotation.	• retention of structural diversity and habitat • retention of late-successional understoreys • more hollows for fauna • large log habitat • improved aesthetics • lower safety risk than dispersed retention • natural seed supply • special species timber supply	• more coupes and hence more roads and more burns required for the same area harvested compared to clearfelling • difficult fire management
Single-tree/small-group selection (ground) Retain >75% forest cover at all times, permanent primary snig tracks, openings less than one tree height wide, harvest c. 40 m^3 ha^{-1} every 20 years (based on primary production of 2 m^3 ha^{-1} $annum^{-1}$), heaping of slash, mechanical scarification, no burning, natural seedfall (SGS)	WR5D	• Harvest mature trees as safely as possible, with adequate growth of eucalypt and special species regeneration and enhanced biodiversity while maintaining a continuous tall forest cover.	• retention of structural diversity and habitat • improved aesthetics • natural seed supply • greater special species timber supply	• higher safety risk to harvesters • high harvest cost • more coupes and hence more roads required for the same area harvested compared to clearfelling • reduced eucalypt regeneration stocking and growth • damage at subsequent harvests • fire hazard from unburnt slash
Group selection (ground) Retain 70% forest cover, permanent primary snig tracks, harvest 30% of the canopy cover every 30 years, permanent retention of at least 10% of the area, openings twice tree height wide, low intensity burn, natural seedfall.	WR8G	• Harvest mature trees as safely as possible, with adequate growth of eucalypt and special species regeneration and enhanced biodiversity while maintaining a continuous tall forest cover.	• retention of structural diversity and habitat • improved aesthetics • natural seed supply • greater special species timber supply	• more coupes required for same area harvested • more roading • reduced eucalypt regeneration stocking • more burns • damage at subsequent harvests
Control	8J 8K		study long term change	

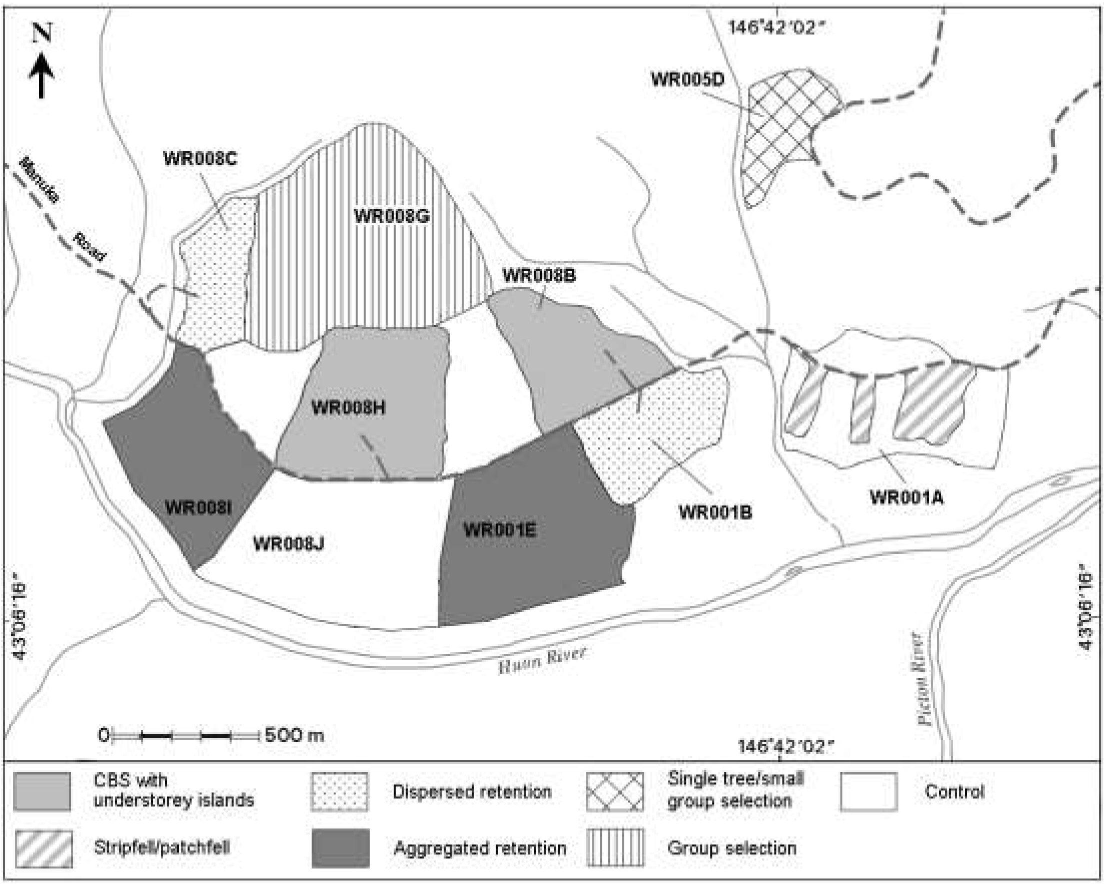

Figure 2.1. Layout of the coupes in the Warra silvicultural systems trial.

Table 2.2. Harvesting, burning and sowing dates.

Coupe	Harvest start	Harvest end	Burnt	Sowing date or natural
WR8H	26 October 2000	15 March 2001	7 April 2001	Aerially sown 16 April 2001
WR8B	17 August 1998	3 December 1998	26 March 2000	Aerially sown 1 April 2000
WR1A (F)	3 March 1999	15 April 1999	26 March 2000	Natural
WR1A (N)	29 April 1999	10 May 1999	27 March 2000	Natural
WR1A (L)	27 May 1999	4 June 1999	7 April 2000	Natural
WR1B	26 November 1997	6 March 1998	28 April 1998	Natural
WR8C	28 September 1999	2 November 1999	9 April 2000	Natural
WR1E	26 March 2003	5 August 2003	20 April 2004	Natural
WR8I	26 November 2002	12 April 2003	27 April 2003 (failed) 21 April 2004	Natural
WR5D	1 May 2001	21 May 2001	No burn	Natural

WR8G	9 January 2006	2 February 2006	27 March 2007	Natural

Figure 2.2a. The Warra silvicultural system trial, prior to establishment of any of the treatments (1997).

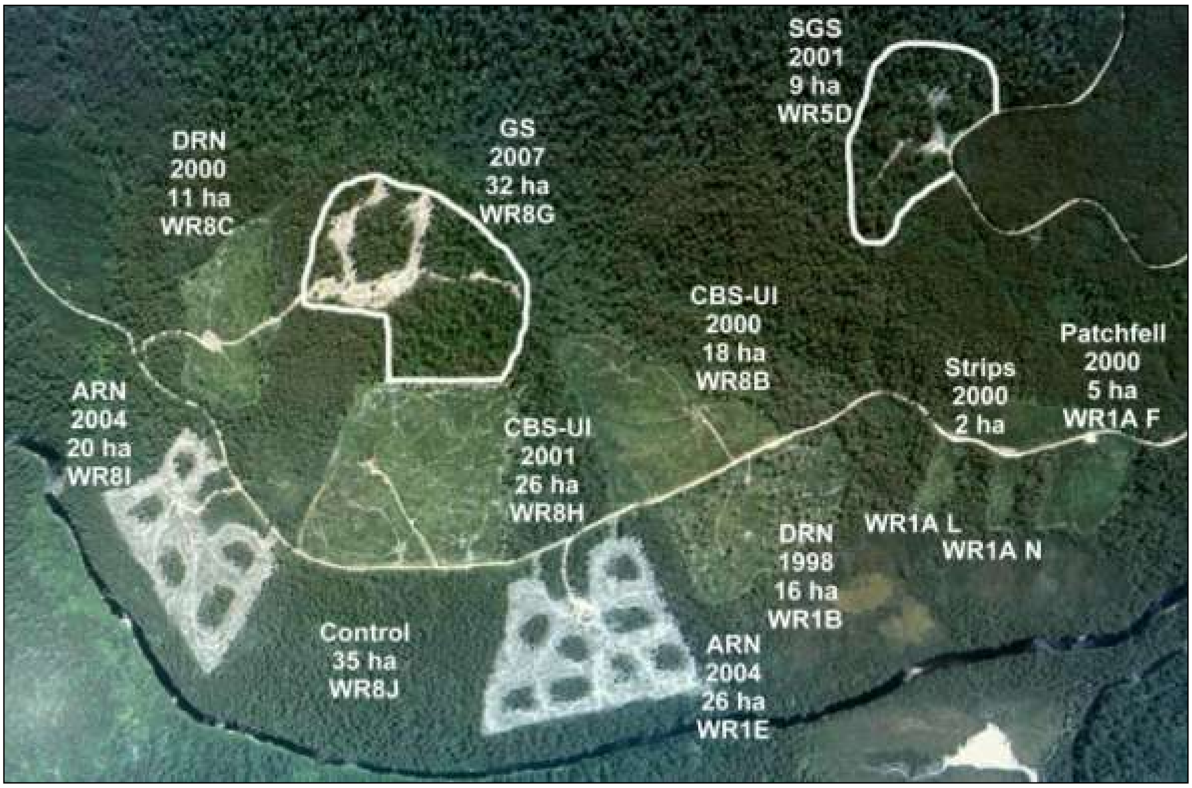

Figure 2.2b. The Warra silvicultural system trial, after establishment of all of the treatments (2007).

from year to year also created some difficulties; for example, the fire intensity during slash burning in the first dispersed retention coupe was much lower than in the second coupe.

Harvesting was delayed on a number of occasions due to difficulties in finding suitable harvesting contractors who were prepared to try alternatives to clearfelling. Harvesting was delayed for a year when the early onset of prolonged autumn rains meant that the first clearfell burn and sow with understorey islands coupe could not be burnt; safe burning protocols restrict the opening of adjacent coupes when harvesting debris in the first coupe has not been burnt (Forestry Tasmania 2005). Harvesting was delayed for another year when the Tahune airwalk proved to be such a resounding success that it was deemed not possible to take harvested timber past it. A new bridge was erected over the Weld River to provide an alternative route for timber cartage. The aggregated retention treatment took longer to establish than anticipated. In 2007 all the treatments except the second group selection (WR8G) were at least three years of age. WR8G will be three years of age in 2010.

In attempting to replicate each treatment the most difficult part of the operation to control was the regeneration burn, which is strongly influenced by the weather conditions over the two or three months preceding the burn. This affects the dryness of the soil and in turn the dryness of the harvesting debris. The weather on the day of the burn also has an influence. Given that the weather is uncontrollable, the intensity of the burn can only be controlled by the decision to burn or not to burn on a particular day, and then by the lighting pattern and time of ignition once the decision to burn is made (Forestry Tasmania 2005). Consequently there were significant differences in the burning outcomes between some of the treatment replicates.

The harvesting and burning operations

General considerations for slash burning – fuel moisture sticks

Weather conditions at the time of burning each coupe are given in Table 2.3. The 'sticks' referred to in the table are hazard or fuel moisture sticks. 'Fuel moisture sticks comprise a set of three pine rods, oven dried at 40°C to 0% moisture content, loosely wired together and trimmed to weigh exactly 100 g dry weight. When placed in the field these sticks absorb moisture from rain and respond to changes in atmospheric humidity in a similar manner to fine fuels [material less than 6 mm thick (Forestry Tasmania 2005)]. By weighing the sticks, any additional weight over 100 g is all absorbed moisture and so is numerically equal to the moisture content per cent of the sticks' (Forestry Tasmania 2005). Sticks are placed both in the coupe, amidst the harvesting debris, and in the adjacent unharvested forest at least 60 m from the edge (hence 'Sticks forest/coupe' in Table 2.3). The relative moisture differential between the harvesting debris and the adjacent unharvested forest is an important consideration in determining whether or not to proceed with a regeneration burn. When the sticks in the harvesting debris are at 14% moisture content or less, a fire in those fuels is likely to be quite hot. At 14 to 16% the fire should be less intense and at 17% or above the fuel will be difficult to light. Burning is generally undertaken a few days after rain when the forest, which dries out more slowly than the harvesting debris, is still too wet to burn but the harvesting debris is sufficiently dry. This approach aims to minimise the risk of fires spreading into the adjacent unharvested forest.

Table 2.3. Weather conditions at the time of burning each coupe.

Coupe	Date	Moisture content of sticks, forest/ coupe (%)	Ignition time	Temp (^{o}C)	Wind direction	Wind speed (km h^{-1})	RH[1] (%)	Cloud cover (eighths)
WR8H	7 April, 2001	39/11	16:51	20	NW	<5	74	7/8
WR8B	26 March, 2000	22/16	12:56	19	NW	0	52	7/8
WR1A (F)	26 March, 2000	21/15.5	16:00	17	SE	0	80	7/8
WR1A (N)	27 March, 2000	28/18	11:05	17	-	0	90	8/8
WR1A (L)	7 April, 2000	29/16	13:35	16	WNW	10	68	7/8
WR1B	28 April, 1998	32/19	13:25	16	NW	<1	80	7/8

WR8C	9 April, 2000	24/17	13:46	20	WNW	<10	66	1/8
WR1E	20 April, 2004	35/18	15:20	15	W	<2	59	7/8
WR8I	26 April, 2003	33/23	14:41	17	N	<5	72	3/8
WR8I	21 April, 2004	35/15	15:30	18	W	<3	65	3/8
WR5D	No burn							
WR8G	27 March 2007	20/14	14:50	20	N	<5	59	1/8

Note 1. RH; relative humidity.

The window of opportunity to achieve such burning is short, and is generally restricted to the period between the first autumn rains, and such time later in the season, usually sometime in May, when it becomes too wet and cold to burn.

On the day when it was intended to burn the coupe, an observer took regular measurements of the sticks. The observer also took regular measurements in the open in the centre of the coupe, of the temperature, wind speed and direction, relative humidity and cloud cover (Table 2.3). All these variables were considered in the decision to burn, or not. To protect the retained trees, strips, understorey islands and aggregates in the different treatments within the trial, most of the burns were conducted under more conservative conditions (higher stick readings, lower temperatures, higher relative humidities and lower wind speeds) than would be required for routine high intensity burning.

Clearfell burn and sow with understorey islands. First replicate, WR8H

The harvesting prescription for WR8H called for the coupe to be clearfelled, burnt in a high intensity burn and sown, except that four understorey islands each of 40 m by 20 m were to be retained undisturbed by machinery through the course of the harvesting. Understorey islands were first advocated for use in wet forests in Victoria by Ough and Murphy (1998). The main purpose of understorey islands was to enhance the survival in the regenerating stand of plant species that reproduce predominantly via vegetative means, and to maintain the presence in the regenerating stand of oldgrowth understorey structures such as large manferns and large old understorey shrubs favoured by epiphytic ferns. In addition, retained understorey islands may serve as a source of propagules for recolonisation of harvested sites.

The contractor was permitted to fell eucalypt trees out of the understorey islands if they could be felled clear of the islands without causing undue disturbance to the understorey. The top half (topographically speaking) of WR8H was harvested by the same contractor who harvested WR1B, WR8B and WR8C, but the lower half was harvested by a different contractor. Both contractors used an excavator in the forest for ‘scrubbing’ (laying the understorey down to improve access, visibility and safety for the faller) and forwarding (setting logs on the side of the snig tracks ready for snigging), a small bulldozer for snigging the logs to the landing, and another excavator on the landing for processing (debarking, trimming, sorting and loading) of the logs. The contractor in the top half of the coupe used corded and matted snig tracks, where woody material is used to protect the soil on the tracks from compaction and erosion (Wilkinson 2000); the contractor in the lower half did not. Four understorey islands were retained during the course of the harvesting, three in the eastern side of the coupe and one towards the western side. Windthrow of the understorey trees and large shrubs in the understorey islands had a dramatic impact on the structural integrity of the islands during the period between the completion of harvesting and the regeneration burn. By the time of the regeneration burn most of the taller understorey had been windthrown.

Between the completion of harvesting and the subsequent burning, a bare mineral earth firebreak approximately 6 m wide was mechanically cleared around the perimeter of the coupe. The heaped fuels arising from the firebreak created a windrow which also extended around the perimeter. A high intensity burn was lit by aerial drip torch; all four understorey islands were burnt.

Second replicate, WR8B

WR8B was harvested to the same prescription as WR8H. Harvesting commenced in August 1998 and was completed by December of that year. The harvesting was conducted by the same crew that harvested the top of WR8H, using the same machinery configuration. The understorey islands in WR8B were arranged near the western side of the coupe, so were more protected by the adjacent unharvested forest from the prevailing westerly winds than those in WR8B and they were intact at the time of the regeneration burn.

WR8B had firebreaks and associated windrows prepared as elsewhere. Following an unsuccessful attempt to burn the coupe in 1999, the coupe was lit in 2000 by aerial drip torch and a high intensity burn was successfully achieved. Three of the four understorey islands were burnt.

Patchfell and stripfells, WR1A

Stripfells, where harvested strips about two tree heights wide are alternated with retained strips of similar width, are designed to provide seed and shelter for regenerating adjacent harvested areas (Smith *et al.* 1997). This is seen as particularly advantageous in mixed forests, which are forests comprising mature eucalypts over a well developed understorey dominated by rainforest species (Gilbert 1959), because the proximity of the retained forest to the harvested strips provides greater opportunities for rainforest species recruitment compared to routine CBS operations in which rainforest species are disadvantaged (Hickey and Wilkinson 1999b). The patchfell was established within the SST primarily to explore the maximum colonisation distance of eucalypts.

In WR1A, one 200 m wide patchfell (about five times average tree height) (WR1A F) and two 80 m wide stripfells (about twice average tree height) (WR1A N and WR1A L), all about 250 m deep were felled and then harvested using a Madill cable yarder. Two excavators were used for processing the logs at the landing. The harvested stripfells and the patchfell were separated by retained unharvested belts of forest, also about two tree heights equivalent in width (c. 80 m). The understorey in the upper two-thirds of the retained belts was dominated by rainforest species, while the lower third had a tall sclerophyllous shrub understorey.

All three sections of WR1A (F, N and L) had firebreaks and associated windrows prepared as elsewhere. The patchfell (WR1A F) was lit by aerial drip torch in a high intensity burn, which significantly reduced the harvesting debris. The fire spilt into the top of the eastern belt, between the patchfell and WR1A N, and burnt overnight into the top corner of WR1A N. The rest of WR1A N was hand lit the following day. The burn again significantly reduced the harvesting debris, and there were no escape-fires into the surrounding forest. Subsequent rain prevented lighting of WR1A L until 7 April 2000. This strip was also hand lit, under similar conditions to WR1A N (Table 2.3). The western side of the strip, which was shaded by the adjacent unharvested forest, was particularly difficult to light.

Dispersed retention. First replicate WR1B

The original harvesting prescription called for dispersed retention (DRN) of evenly distributed trees in order to retain approximately 10 – 15% of the basal area of the original standing forest, comprising a mixture of oldgrowth and regrowth trees. The objective of retaining the trees in a dispersed pattern was to enhance structural diversity within the coupe and to improve the post-harvest aesthetics. Details of the selection of the retained trees are given in Neyland (2004); essentially trees (both regrowth and oldgrowth) were retained on an even spacing of about 30 m. The harvesting was conducted by the same crew that harvested the upper section of WR8H and all of WR8B, using the same machinery configuration. The harvesting crew were experienced only in clearfelling operations in regrowth forest and found it uncomfortable working beneath a retained canopy. Three meetings were called on-site to discuss the safety issues, involving a Workplace Standards Authority expert, the harvesting supervisors, the harvesting crew and the silvicultural team. Following investigations led by the Workplace Standards Authority (WSA) expert (WSA is the State safety regulator), the prescription for WR1B was revised; the revised prescription to be applied to the rest of WR1B and to all of WR8C (the second DRN coupe) was that the contractor was not required to retain oldgrowth trees unless he felt it was safe to do so (see also below under WR8C).

Following completion of harvesting (March 1998), an excavator was used to rake the harvesting debris away from the base of the retained trees. Firebreaks and associated windrows were prepared as elsewhere.

The fire in WR1B was hand-lit late in the burning season (28 April 1998, see also Marsden-Smedley and Slijepcevic (2001) for details of the post-burning fuel load assessment), by ten people with drip torches proceeding slowly across the coupe in a broken line. The weather conditions were deliberately very conservative due to a desire not to burn the retained trees if possible. The slash sticks indicated a high moisture content of 19% and the temperature was low (16ºC). The fire was of low intensity. Only slash that was directly lit burnt; the fire did not travel freely across any debris that was in contact with the soil. Perhaps one and a half hours after the first lighting, the fire was drawing cooler moist air in from the surrounding forests and the fire intensity decreased. Unshaded sections of the windrow around the perimeter of the coupe and the accumulated debris around the landing were the only areas that burnt vigorously. Additional lighting was attempted the next day, but very little additional area was burnt.

Following completion of the harvesting and burning, 144 trees had been retained on the 15 ha. Of these trees 57% were oldgrowth and 43% regrowth and the total retained basal area was 8.7 m^2 ha^{-1}, equivalent to (12%) of the original basal area of 72.5 m^2 ha^{-1}. In the first three years since completion of harvesting, 15 trees (13 regrowth and two oldgrowth) were windthrown and a small number of oldgrowth trees died or showed a substantial loss of vigour. The retained basal area was thus reduced further to 8 m^2 ha^{-1} (Neyland 2004), but remained within the original prescription.

Second replicate WR8C

The harvesting prescription for WR8C was originally intended to be the same as that for WR1B; retention of 10 – 15% of the basal area of the standing forest as evenly dispersed trees, comprising a mixture of oldgrowth and regrowth (Hickey *et al.* 2001). However, as mentioned above, safety issues which arose during the harvesting of the first dispersed retention coupe (WR1B), led to a variation from the original harvesting prescription. Where oldgrowth trees which had been marked for retention were deemed to be dangerous, the faller was permitted to fell the tree (or ask that it be felled using explosives) and to substitute it with a retained regrowth tree to maintain the appropriate number and spacing of retained trees on the coupe. It was acknowledged that retaining regrowth instead of oldgrowth trees would mean that whilst the target number could be retained, it would be difficult to achieve the original basal area target as the regrowth trees had a much smaller diameter at breast height than the oldgrowth trees. It was also anticipated that the likely seedfall on the coupe from the retained trees could be reduced as the seed crop in the regrowth trees was lighter than that in the oldgrowth trees. The harvesting was undertaken by the same crew that completed WR8H (top), WR8B and WR1B, using the same machinery. Firebreaks and windrows were prepared as in previous coupes.

Following completion of harvesting (November 1999), the coupe was burnt by a hand-lit fire, late in the burning season (9 April 2000, see also Marsden-Smedley and Slijepcevic (2001) for details of the post-burning fuel load assessment). As for the first dispersed retention coupe, the aim of the planned low-intensity burn was to reduce the amount of harvesting debris and create receptive seedbed, whilst keeping the retained trees intact. The slash sticks were at 17%, which indicated that the fire intensity should have been low. However, on the eastern side of the coupe in particular, which receives more of the afternoon sun and so was drier than the more shaded western side, the fire was much hotter than desired. The fire ran into the adjacent unharvested forest and burnt about 3 ha outside the coupe. Near the western side of the coupe the fuel that was shaded by the adjacent unharvested forest proved difficult to ignite.

Following completion of the harvesting and burning, 85 trees had been retained over the 9.5 ha. Of these trees, 31% were oldgrowth (compared to 57% in WR1B) and 69% regrowth (43%). The total retained basal area was 4.5 m^2 ha^{-1}, 6% of the original basal area of 74 m^2 ha^{-1}. In the first three years since completion of harvesting, 12 trees (eight regrowth and four oldgrowth) were windthrown and 22 trees died, presumably from fire damage. The retained basal area was thus reduced further to 2.9 m^2 ha^{-1} (Neyland 2004), or 4% of the original basal area, significantly below that specified in the original prescription.

Aggregated retention. First replicate, WR1E

The harvesting prescription for the aggregated retention (ARN) coupes called for 30% of the planned area of each coupe to be retained as unharvested aggregates of half to one hectare each, with the remainder of the coupe to be felled. A low intensity burn was planned for the first autumn following completion of the harvesting, and regeneration was to originate from natural seedfall.

The objective of the aggregated retention treatment was to maintain structural and floristic diversity within the coupe and to improve the coupe aesthetics, whilst also addressing the safety issues that were encountered with dispersed retention. By clumping the retained trees into aggregates the issue of working beneath a retained canopy was not expected to arise. Harvesting around aggregates was expected to be little different to working near streamside reserves or coupe edges. It was recognised quite early that regeneration burning in such coupes would be a challenge.

Harvesting of both of the aggregated retention coupes was by the same contractor, who was new to the trial. The contractor used an excavator to assist with falling and scrubbing, a skidder to take logs to the landing and another excavator on the landing for processing and loading of logs. As this was a new type of operation both for the harvesting method and for the contractor, he was paid an hourly rate rather than the more usual production rate. Harvesting proceeded without incidents in both coupes.

The harvesting prescription was achieved in WR1E, with about 30% of the area retained in eight aggregates of about one-quarter to one hectare in size. Firebreaks and windrows were prepared as in previous coupes. In addition, any harvesting debris and ground cover species (mostly *Bauera rubioides*) around the retained aggregates was lightly raked back by an excavator from the edge of the aggregates, without unduly disturbing the soil.

The burn was lit in the middle of the afternoon using a helicopter with an aerial drip torch, and was completed as the day progressed by hand crews working their way around the perimeter of the coupe. The main problems with lighting occurred in the more shaded areas of the coupe. Reasonable fuel reduction was achieved. There were minor incursions of the fire into the aggregates.

Aggregated retention. Second replicate, WR8I

WR8I was harvested to the same prescription and by the same crew as WR1E. At the completion of harvesting approximately 30% of the coupe area had been retained in five aggregates of one-third to one hectare each.

The first attempt to burn the harvesting slash in WR8I in the autumn immediately following the completion of harvesting was unsuccessful. Only an open area in the centre of the coupe that had been harvested relatively early in the history of this operation burnt reasonably well. Most other areas of the coupe burnt poorly, if at all. Some of the fuel in the coupe was not only still green, but was wet with dew, which did not dry off during the day due to shading by the adjacent forest. Additional unsuccessful attempts were made to burn parts of the coupe on the day after the first attempt. Subsequent rain ruled out any further attempts at burning the coupe that year.

After considerable discussion about the best approach to burning aggregated retention coupes following the poor burn the previous year, slash on the coupe was rough heaped using a small

(12 t) excavator. The aim of the heaping was to enable more intense fires in the heaps and to enable more intense burning of those areas that again, as the season progressed, were subject to shade from the adjacent forest. It was thought that heaping would allow a more intense burn overall than would a broadcast low intensity fire, whilst still retaining the aggregates in a largely unburnt state. The second burn was lit using a helicopter with an aerial drip torch in the middle of the afternoon, and was completed as the day progressed by hand crews working their way around the perimeter of the coupe. Heaps that were heavily shaded would still not light. Four of the aggregates had minor burning impacts.

Single tree/small group selection, WR5D

The first single tree/small group selection (SGS) coupe, WR5D, was harvested in May 2001, to a prescription that was developed by representatives of interested community groups together with the silvicultural team. The final prescription, after two years of development, called for a selective harvest of mature to over-mature trees, using permanent snig tracks and taking a notional harvest volume of about 40 m^3 ha^{-1} every 20 years, in perpetuity. As this was to be the first selection cut on a coupe of 10 ha, it allowed for a harvest of about 400 m^3. Safety was considered to be of paramount importance, as it is in all forest operations, and where necessary it was agreed that trees could be felled using explosives. The community group determined that burning of the harvesting debris was unnecessary and that the coupe could be regenerated by heaping the harvesting debris and by raking the exposed seedbed with the tines of an excavator. Harvesting was undertaken by a contractor paid on an hourly rate, as the operation was deemed too dangerous to be undertaken on a production rate. At the completion of harvesting, a total of 440 t of wood had been recovered, which was very close to the target. The total area disturbed during the harvesting was 1.6 ha. Since there was no burning, no firebreaks were created.

A review of the operation including advice from experts from the Workplace Standards Authority deemed that the operation applied to WR5D was too dangerous to be repeated, largely due to the constant need to be working under a canopy that had been disturbed by the felling of adjacent trees. The site was formally closed for six months following completion of harvesting to allow loose material in the canopy time to fall. The site was inspected after six months had elapsed and was deemed to be sufficiently safe to allow access for research purposes.

Group selection, WR8G

The second group selection coupe was the final coupe to be harvested. The prescription for harvesting the coupe was developed by the silvicultural team together with a group of interested people, together referred to as the design group; some were representatives of particular community groups, others simply interested participants. Some members of the design group had been involved with the harvesting of WR5D, and took some lessons from that experience into the planning of WR8G. The agreed approach was again to base the harvesting on the expected long term productivity of the site, but also to better recognise the requirements of eucalypts for natural regeneration, and to pay closer attention to safety. Thus the group supported openings that were about two tree heights wide, harvesting about one third of the available area on a notional return cycle of about 30 years, so three harvests over 60 years would harvest 90% of the area, with 10% never to be cut. The harvesting slash was to be burnt following preparation of that slash with excavators in order to protect the unharvested forest from the burn. One of the design group members objected to burning, so the very eastern arm of the coupe was left unburnt. This will provide a demonstration site to show the difference between burnt and unburnt areas over time.

The planned coupe boundary for WR8G encompassed about 30 ha. Instead of the planned 9 ha only about 4.5 ha had been harvested at the completion of the operation. Otherwise the harvesting met the design group's specifications. The openings were mostly about two tree heights wide and the harvesting debris was prepared for burning in accordance with the design group's specifications.

In all the harvested areas an excavator was used to rake the harvesting debris away from the adjacent unharvested forest, and to pile the debris into rough heaps. WR8G was hand lit under moderate conditions by a team of six people over two hours. The burn successfully reduced the volume of slash. There was a minor excursion into the adjacent forest, but this rarely ran in more than about 10 m.

An on-site meeting of the design group was convened after completion of the harvesting and again after completion of the burning and all the design group members who attended the site meetings confirmed their approval of the outcomes.

Sowing

WR8B and WR8H, the two CBS with understorey islands coupes, were aerially sown following standard procedures shortly after the completion of burning (Table 2.2). All the other coupes were regenerated by relying on natural seedfall from the retained trees. Seedfall is discussed in more detail in Chapter 7.

Each of the silvicultural systems applied in the trial are shown in the following photos.

Photo 2.1. WR8B (clearfell burn and sow with understorey islands) post-harvesting and pre-burning. Two of the understorey islands are indicated by arrows. This view is from the landing looking west.

Photo 2.2. WR8B post harvesting and burning. The understorey islands are indicated by arrows. The two understorey islands to the top of the picture are the islands in photo 2.1.

Photo 2.3. WR8B five years after the burn. *E. obliqua* saplings in foreground.

Photo 2.4. WR1A (F) (patchfell) post-harvesting and pre-burning. Note the extensive fireline between the harvested area and the adjacent unharvested forest.

Photo 2.5. WR1A (F) post harvesting and burning.

Photo 2.6. WR1A (F) at age six years, looking northwest. The bright spot top centre is the landing. Note the abundance of eucalypt regeneration (darker green) near the retained forest left (west) of photo and the relative paucity of regeneration to the right (east), further from the retained forest.

Photo 2.7. WR1A (N) and (L) (stripfells) post harvesting and burning, aerial view.

Photo 2.8. WR1A (N) post harvesting , ground view.

Photo 2.9. WR1A (N) at age five years.

Photo 2.10. WR1B (dispersed retention) at the completion of harvesting, and before burning, aerial view.

Photo 2.11. WR1B at the completion of harvesting, and before burning, ground view.

Photo 2.12. WR1B, age five years. Photo taken from close to the same position as above photo.

Photo 2.13. WR1E (aggregated retention) at the completion of harvesting and burning, aerial view.

Photo 2.14. WR1E at the completion of harvesting, ground view.

Photo 2.15. WR1E at the completion of harvesting and burning, ground view, age two years.

Photo 2.16. WR5D (single tree/small group selection). The landing (top right) and one of the larger gaps (left) are indicated by arrows.

Photo 2.17. WR5D post harvesting, in one of the gaps.

Photo 2.18. WR5D, the same gap at age five years. Note the absence of eucalypt regeneration.

Photo 2.19. WR8G (group selection), post-harvesting and pre-burning. (The coupe to the left is the second dispersed retention coupe, WR8C.) The arrow indicates the location of the photographer for the two pictures below.

Photo 2.20. WR8G post-harvesting looking down the main harvested ‘fairway’. The green funnel-shaped object front centre is a seed trap.

Photo 2.21. WR8G, post harvesting and burning.

Chapter 3. The pre-harvesting vegetation of the Warra silvicultural systems trial

Introduction

The vegetation of the Warra silvicultural systems trial area is dominated by wet eucalypt forest (Corbett 1997). Wet eucalypt forests are perhaps the best studied of the different ecosystems in Tasmania: the majority of the timber produced in Tasmania is harvested from these forests. There has been a succession of inquiries into Tasmanian forests and its forest industry over the last 40 years, culminating in the Comprehensive Regional Assessment process (Public Land Use Commission 1996) that preceded the Regional Forest Agreement (Commonwealth of Australia and State of Tasmania 1997). Many of these inquiries have funded associated studies, that together have produced a significant knowledge base about the wet eucalypt forests of Tasmania (e.g. Williams 1987; Wells 1989; Kirkpatrick *et al.* 1994).

The earliest detailed study was that of Gilbert (1959), who examined the patterns and processes within a mosaic of rainforest, mixed forest, wet forest and plains in the Florentine Valley, a high rainfall area to the west of Hobart. In the absence of disturbance by fire, the understorey of the wet eucalypt forest can become dominated by rainforest tree species, and as the eucalypts senesce and die, the forest gradually becomes pure rainforest (Gilbert 1959). Wet forests are most extensive in Tasmania, and indeed in south-eastern mainland Australia, where rainfall is between 1000 and 1500 mm per year, and soil fertility is high (Ashton 1981a; Wells and Hickey 1999). In areas of higher rainfall (>1500 mm), succession to rainforest can be relatively rapid and wet eucalypt forest becomes restricted to more exposed, and hence more fire prone, sites. Below 1000 mm per annum rainfall wet forest occurs only in topographically protected sites amidst drier eucalypt forests (Duncan and Brown 1985).

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Methods

Pre-existing data

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- *Eucalyptus obliqua* wet sclerophyll forest with an understorey dominated by *Leptospermum lanigerum, Melaleuca squarrosa, Nematolepis squamea, Bauera rubioides* and *Gahnia grandis* (similar to OB3 *sensu* Duncan and Johnson (1995) and OB0111 *sensu* Kirkpatrick *et al.*, (1988)).

- *E. obliqua* mixed forest with an understorey of rainforest species typical of thamnic rainforest (Jarman *et al.* 1984), particularly horizontal scrub (*Anodopetalum biglandulosum*).

- *E. obliqua* mixed forest with an understorey of rainforest species typical of callidendrous rainforest (*sensu* Jarman *et al.* 1984), particularly myrtle (*Nothofagus cunninghamii*) and sassafras (*Atherosperma moschatum*).

The three communities were designated as G type (for *Gahnia grandis* dominated understoreys), T type (for thamnic rainforest understoreys) and C type (for callidendrous rainforest understoreys), respectively.

Establishing the vegetation quadrats

The trial area was subdivided into 10 planned coupes each of between 15 and 30 hectares, with roads, streams, rivers and/or poorly drained areas setting most of the coupe boundaries (Figure 3.1). Foot tracks were hand-cut through and sometimes around each planned coupe. The floristic quadrats, each of 10 m by 10 m, were established within each planned coupe at a target density of about one quadrat per hectare, often achieved by spacing the quadrats roughly evenly along the foot tracks (Figure 3.1). The same quadrat size was used for the Kirkpatrick *et al.* (1988) study of wet forests and is of a practical size for wet eucalypt forests. Two observers stationed on the two diagonally opposite corners of a 10 m by 10 m quadrat can make relatively accurate assessments of the projective foliage covers of each of the species present because they can see each other and most of the plot at the one time. For larger quadrats this would not be possible, and in smaller ones the sample size would be reduced to an unacceptable level.

At each planned quadrat location a helmet was tossed blindly into the forest and the quadrat was located from the point where the helmet fell, that point becoming one corner of the quadrat with the side of the quadrat being located parallel to the foot track. A blaze was cut into the base of the nearest mature eucalypt between the foot track and the quadrat, the bearing and distance from the tree to the nearest corner of the quadrat was recorded and a sketch map was made showing the layout of the quadrat, the blazed tree and the track. The GPS location of the tree was recorded, to assist with relocation post-harvesting. All of the floristic data was collected by the same observer.

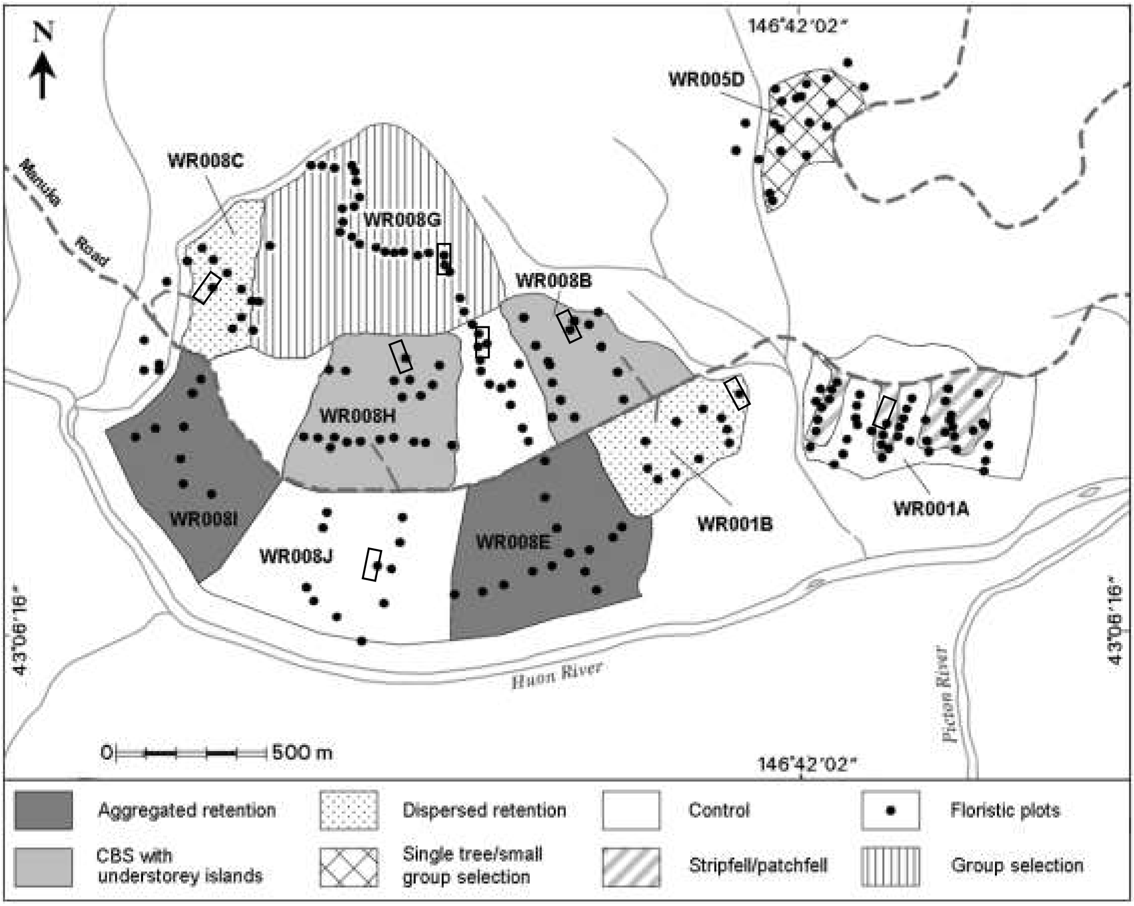

Figure 3.1. The Warra silvicultural systems trial showing the layout of the coupes and the positions of the floristic quadrats. The 50 by 20 m inventory and control plots within the trial area are marked (…). The external control plots are not shown.

Fifty metre by twenty metre inventory plots were established in most coupes, and these were overlaid by a set of ten, 10 m by 10 m floristic quadrats. Inventory plots were not established in WR5D, WR8! and WR1E where a different approach to inventory was applied. Never-to-be-harvested control plots were also established using the same layout. Control plots were established both within the boundaries of the SST ('internal' control plots) and outside the SST but as close to the trial as possible, within areas that were excluded from future harvesting activities, and within vegetation that was identified as being as similar as possible to that vegetation type within the SST ('external' control plots). The location of all these plots was fixed as for the quadrats above.

Internal and external control plots were established in each of the three preliminary vegetation types (as described above), with the exception of an internal C type control, for which a suitable location could not be found. Undisturbed quadrats within C type communities within the trial area served as internal controls for this vegetation type. The external G control was established after this pre-harvesting vegetation analysis was completed. All the quadrats were established and measured prior to the commencement of harvesting. The final data set comprised 257 quadrats (123 G type, 78 T type and 56 C type).

As each coupe was established, there was often variation between the planned coupe boundaries, and the final harvest boundary. For example the boundaries of two coupes (WR8C and WR8B) were adjusted inwards when previously unknown streams were located within, but close to the edge of, the planned coupe. In the stripfells and patchfell coupe (WR1A), quadrats were established throughout the planned harvest area and then the two strips and the patchfell were demarcated, leaving some quadrats within the belts retained between the harvested strips and patch (Figure 3.1). Consequently, in addition to the deliberately established control plots, there is also a smaller set of quadrats that were never harvested, and that were also measured repeatedly.

Quadrat measurements

In each quadrat, data were collected on the projective foliage cover of each higher plant species present using a modified Braun – Blanquet scale (Mueller-Dombois and Ellenberg 1974) (1 = 0 to 1%, 2 = 2 to 5%, 3 = 6 to 25%, 4 = 26 to 50%, 5 = 51 to 75% and 6 = 76 to 100%) and the projected foliage cover (%) of each layer of the vegetation. Environmental data were collected for slope (degrees of elevation or declination), aspect (degrees), landform (ridge, knoll, upper slope, lower slope, flat, gully or creekline), and rock cover (%).

Isolepis spp., *Juncus* spp., and *Epilobium* spp. were recorded only to genus level, due to the difficulties with field identification of species within these genera. Juvenile (post-cotyledon stage) *Acacia* and *Lepidosperma* cannot be confidently ascribed to species level so these were recorded as *Acacia* and *Lepidosperma* spp. respectively. In the absence of flowering material some orchids cannot be confidently ascribed to species level, so *Pterostylis* and *Corybas* where they occur were recorded only to genus.

Fire history and soil drainage were determined indirectly. Hickey *et al.* (1999) have documented the fire history of the site from ring counts of understorey species and determined that major fires occurred within the Warra SST in 1898, 1906, 1914 and 1934. Alcorn *et al.* (2001) investigated the ages of each of the eucalypt regrowth cohorts present on each CFI plot (continuous forest inventory, (Lawrence 1978)) within the SST area and determined that regrowth arose from fires in 1898, 1914 and 1934. From the diameters of regrowth stems present on each plot and data from Alcorn *et al.* (2001) and Hickey *et al.* (1999), an estimate was made of the likely number of the known fires (post-1897) to have occurred on that quadrat.

Soil drainage was assessed by Pennington *et al.* (2001a) and a soil drainage value (well drained, moderately well drained, imperfect or poorly drained) was assigned to a vegetation quadrat where survey points for the Pennington *et al.* (2001) study were within 20 m of that quadrat. As soil drainage data were only available for a subset of the quadrats, a separate analysis was undertaken for that subset.

Data analysis

Analysis of the vegetation data was undertaken using PC-ORD (McCune and Mefford 1999). The data were ordinated using detrended correspondence analysis (DCA) and non-metric multi-dimensional scaling (NMS) and classified using two way indicator species analysis (TWINSPAN). Problems identified in TWINSPAN and DCA (Tausch *et al.* 1995; Oksanen and Minchin 1997) have been corrected in the versions of these programs used in PC-ORD (McCune and Mefford 1999). NMS can use random configurations as a starting point or it can take the output from another ordination program as the starting point. In this case, both approaches were used. The configuration provided by DCA was used for one analysis and a full series of random starts was used in another.

Minchin (1987) compared the relative robustness of a range of ordination techniques useful for describing vegetation variation. He compared local non-metric multi-dimensional scaling (LNMS) to detrended correspondence analysis, Gaussian ordination, principal components analysis and principal co-ordinates analysis, and recommended LNMS as the preferred technique for ordination of community data. PC-ORD uses global NMS, which is considered to have stricter criteria than LNMS (Minchin 1987), although McCune and Mefford (1997) state that 'the consequences of the choice of local vs. global NMS have not been fully explored in the literature'.

Non-metric multi-dimensional scaling 'is an iterative search for a ranking and placement of n entities on k dimensions (axes) that minimises the stress of the *k*-dimensional configuration' (McCune and Mefford 1999). The ordination is based on a dissimilarity matrix that is calculated from the matrix of sites-by-species (i.e. the vegetation data). The NMS program calculates the minimum 'stress' in each of 6 dimensions. 'Stress' 'is a measure of the departure from monotonicity in the relationship between the dissimilarity (distance) in the original p-dimensional space [where p is the number of species in the vegetation data] and distance in the reduced k-dimensional space' (McCune and Mefford 1999). To determine the final dimensionality of any given data set, a stress plot, showing the stress for the 1 through 6 dimensional results is produced. Typically the stress is reduced as each successive dimension is added, although the reduction is variable. The NMS program adopts for final use that ordination which achieves no further significant reduction in stress through the addition of further dimensions (defined within PC-ORD as a decrease in stress of 5 on a 100 point scale).

PC-ORD offers a choice of dissimilarity coefficients for use in the ordination. Faith *et al.* (1987) examined the usefulness of a number of dissimilarity coefficients and found that the Bray-Curtis coefficient was among the 'most effective and robust of the measures compared'. The Bray-Curtis coefficient was consequently used for all the analyses presented here. PC-ORD also offers the choice of three 'thoroughness' settings; the fastest computationally is 'quick and dirty', wherein the maximum number of iterations is limited to 75, the instability criterion is set to 0.001, the starting number of axes (i.e. the number of dimensions which are explored by the analysis) is limited to 3, and 5 runs are completed with the real data and 20 with randomised data (in order to compare differing results). The slowest option computationally is the 'slow and thorough' wherein there are 400 iterations, the instability criterion is set to 0.00001, the starting number of axes (i.e. the number of dimensions which are explored by the analysis) is raised to 6, and 40 runs are completed with the real data and 50 with randomised data. A medium setting lies between these two (McCune and Mefford 1999). For exploratory purposes in this study, the 'quick and dirty' settings were used, then for the final analysis (i.e. once any errors in the data had been corrected) the 'slow and thorough' settings were applied.

The ordination provided by NMS was analysed by correlation analysis of the sample variables (slope, aspect, altitude, fire history and for the subset analysis only, drainage) against the ordination scores of the quadrats.

The results of the TWINSPAN analysis were overlaid on the results of the NMS in order to determine the spread of the quadrats through the environmental space and to examine the clustering of the quadrats in order to determine the point at which it was reasonable to stop the TWINSPAN division. Uncontrolled, TWINSPAN will keep dividing each group until there are less than a pre-determined and arbitrary number of quadrats in each group. In this study, the division was stopped at the four group level, and the relationship between the groups was examined using multi-response permutation procedure (MRPP), which tests the hypothesis of no difference between the groups.

As an additional test of the groups produced through TWINSPAN and NMS, cluster analysis was used to produce a hierarchical, agglomerative and polythetic dendrogram of the quadrats. The location of each of the quadrats from the control plots was highlighted on the scatterplot of the quadrats to examine whether the control plots were representative of the vegetation of the SST. The results of the cluster analysis were compared manually to the preliminary classification of the quadrats.

Results

Ordination

The DCA ordination and the two NMS ordinations were very similar in their final result and therefore only one is shown (the second NMS, Figure 3.2). The only difference between the DCA ordination and the random start NMS ordination lay in the orientation of the output – the relationships between the points was the same (i.e. the NMS (1) ordination was the same as the DCA ordination except that

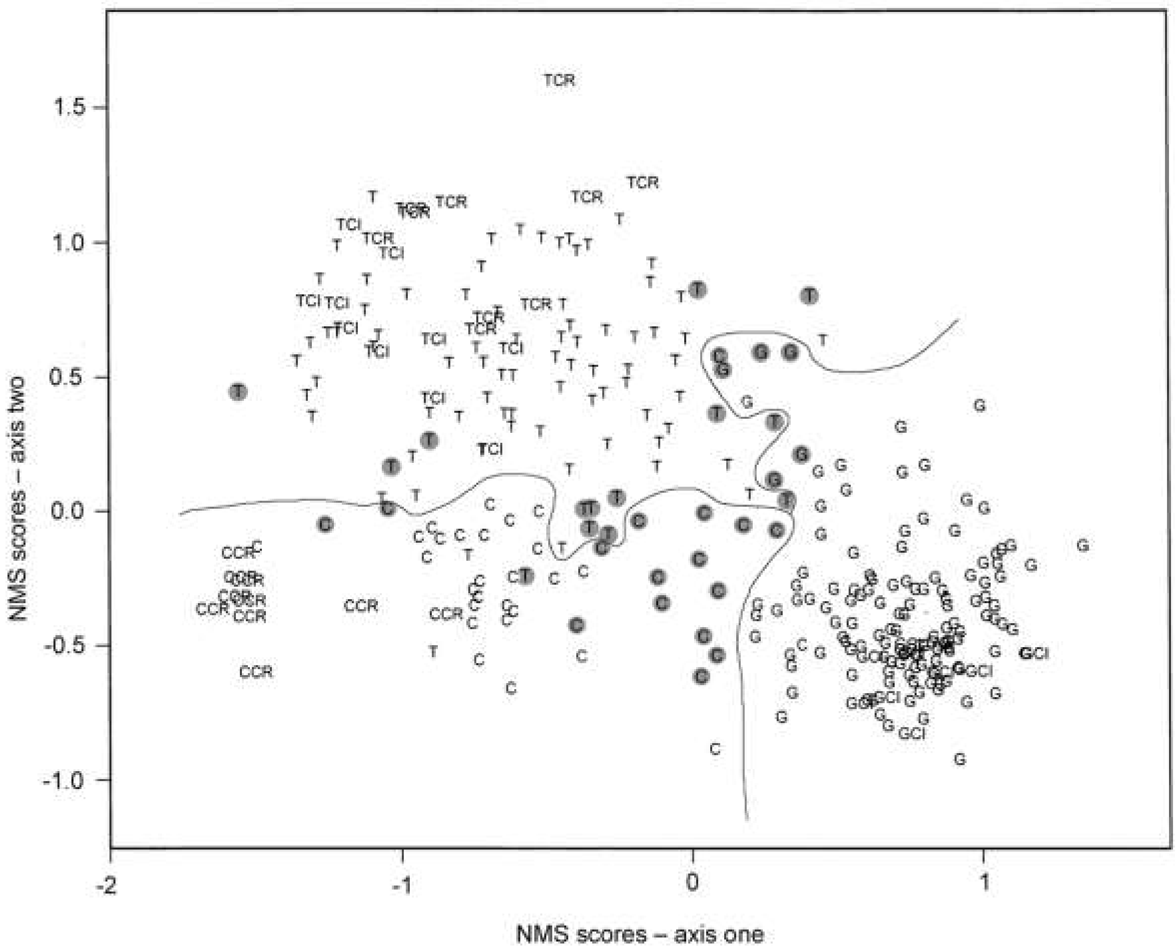

Figure 3.2. NMS ordination of the quadrats. Codes G, C and T as described in the text. The points are labelled G, C or T according to their classification by the cluster analysis. The control plots are labelled: TCR = T control external, TCI = T control internal, CCR = C control external, GCI = G control internal. The shaded quadrats are

those which were classified differently by the cluster analysis and ordination described above, as compared to the preliminary classification. The lines separate the three floristic types.

it was rotated about 60 degrees). The NMS (2) ordination, which used the DCA output as a starting configuration, was almost identical to that produced by DCA. There was a significant reduction in stress between the one dimensional (24) and two-dimensional (16) results but little additional reduction in stress in 3 dimensions (12) which suggests that the data are two-dimensional. The two-dimensional ordination is shown.

The dendrogram produced by the cluster analysis clustered the quadrats into three groups. The three groups are overlaid on the ordination diagram.

Fire history was the only sample variable found to be significantly correlated to the ordination ($r^2 = 0.681$). The subset analysis (not shown) which included the drainage sample variable also found fire history to be the only significantly related variable.

TWINSPAN

The first division of the TWINSPAN classification separated rainforest understorey types, characterised by the presence of *Eucryphia lucida* and *Atherosperma moschatum,* from wet sclerophyll understorey types, characterised by the presence of *Bauera rubioides, Nematolepis squamea* and *Leptospermum lanigerum*. A second division separated the rainforest quadrats into thamnic and callidendrous understorey types. The thamnic types were characterised by the presence of *Anodopetalum biglandulosum* and *Cenarrhenes nitida*, whilst the callidendrous types were characterised by the presence of *Dicksonia antarctica, Histiopteris incisa* and *Hymenophyllum flabellifolium*. These two groups were readily recognisable in the forest and so this division was accepted. A second division of the wet sclerophyll understorey types, separated quadrats which contained scattered individuals of species more typical of later successional forests (*Phyllocladus aspleniifolius, Grammitis billardierei, Hymenophyllum rarum* and *H. peltatum*) from those which lacked such species. The projective foliage cover of these species was rarely greater than 1% and the common and frequent species within both these groups were the same. The different types were not readily recognisable in the forest. Consequently the second division of the wet sclerophyll understorey types was rejected.

Multi-response permutation procedure

The multi-response permutation procedure tests the hypothesis that there was no difference between the groups identified by the TWINSPAN analysis. The test rejected the hypothesis and showed that the difference between the groups was highly significant ($p < 0.0001$).

Comparison of classifications

The shaded quadrats in Figure 3.2 are those which were classified differently by the cluster analysis and ordination described above, as compared to the preliminary classification. It is evident from the figure that all the quadrats which were misclassified were those which lay close to the boundaries of the three groups. As noted above, species more typical of later successional forests are present as scattered individuals in some of the sclerophyll quadrats – such quadrats are inevitably more difficult to assign to one group or another, and all are placed close to the line separating the two groups. Similarly the division between callidendrous and thamnic quadrats is sometimes, but not always, clearly apparent in the forest. In reality there is a continuum from clearly callidendrous type quadrats, to clearly thamnic type quadrats, and there will always be those in the middle that are difficult to classify, and that are classified inconsistently from one procedure to another.

Discussion

The ordination and classification procedures, in combination with the multi-response permutation procedure and the cluster analysis, show strong support for the preliminary qualitative classification of the vegetation. The three identified groups were clearly separated by the ordination, albeit with a zone of overlap. Importantly, these groups are usually easily recognisable in the field, although there can be difficulties in allocating quadrats to either thamnic or callidendrous rainforest, as reflected in the ordination diagram, where such quadrats were sometimes misclassified. Control plot quadrats encompass the full environmental space covered by the vegetation of the SST (Figure 3.2). Any change that results from external influences such as climate change will be reflected by changes in the location of control plots in the ordination space. Changes in the vegetation that are brought about by the harvesting operations will be discernible as changes in location of treatment quadrats in the ordination space relative to the controls.

The correlation analysis of the site variables against the ordination scores indicates that the vegetation within the Warra SST is strongly influenced by the local fire history of each site. Fire behaviour in turn is influenced by local topography and this is reflected in the vegetation (Hickey *et al.* 1999). Below Manuka Rd (Figure 3.1) wet sclerophyll species dominate the understorey vegetation except along the major drainage lines where rainforest elements predominate. Above Manuka Road, wet sclerophyll understoreys dominate the flatter areas and rainforest understoreys extend along the major drainage lines and the steeper south facing slopes which run across the middle of WR8H and WR8B. In Warra 1A, rainforest understoreys are restricted to the steeper slopes and the lower gentler slopes are again dominated by wet sclerophyll understoreys.

Chapter 3. The pre-harvesting vegetation of the Warra silvicultural systems trial

Introduction

The vegetation of the Warra silvicultural systems trial area is dominated by wet eucalypt forest (Corbett 1997). Wet eucalypt forests are perhaps the best studied of the different ecosystems in Tasmania: the majority of the timber produced in Tasmania is harvested from these forests. There has been a succession of inquiries into Tasmanian forests and its forest industry over the last 40 years, culminating in the Comprehensive Regional Assessment process (Public Land Use Commission 1996) that preceded the Regional Forest Agreement (Commonwealth of Australia and State of Tasmania 1997). Many of these inquiries have funded associated studies, that together have produced a significant knowledge base about the wet eucalypt forests of Tasmania (e.g. Williams 1987; Wells 1989; Kirkpatrick *et al.* 1994).

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Pre-existing data

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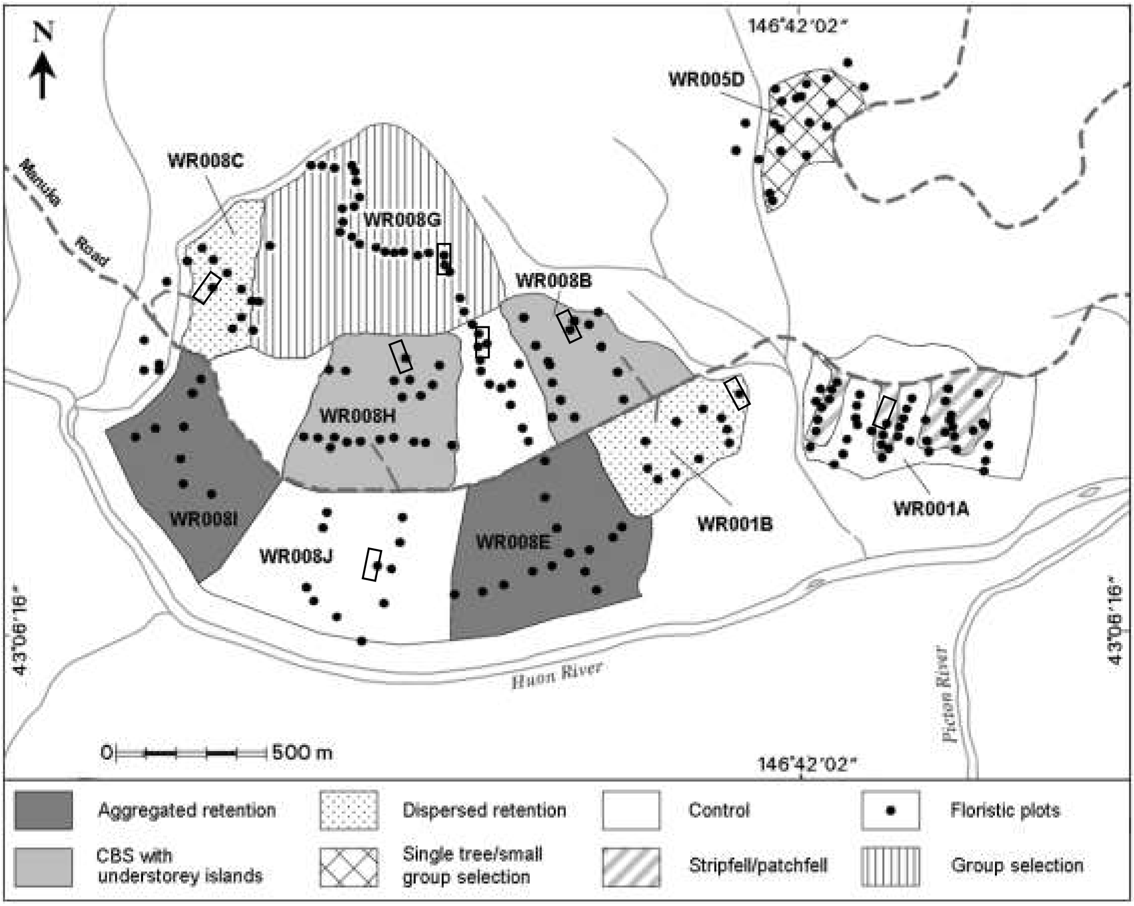

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Analysis of the vegetation data was undertaken using PC-ORD (McCune and Mefford 1999). The data were ordinated using detrended correspondence analysis (DCA) and non-metric multi-dimensional scaling (NMS) and classified using two way indicator species analysis (TWINSPAN). Problems identified in TWINSPAN and DCA (Tausch *et al.* 1995; Oksanen and Minchin 1997) have been corrected in the versions of these programs used in PC-ORD (McCune and Mefford 1999). NMS can use random configurations as a starting point or it can take the output from another ordination program as the starting point. In this case, both approaches were used. The configuration provided by DCA was used for one analysis and a full series of random starts was used in another.

Minchin (1987) compared the relative robustness of a range of ordination techniques useful for describing vegetation variation. He compared local non-metric multi-dimensional scaling (LNMS) to detrended correspondence analysis, Gaussian ordination, principal components analysis and principal co-ordinates analysis, and recommended LNMS as the preferred technique for ordination of community data. PC-ORD uses global NMS, which is considered to have stricter criteria than LNMS (Minchin 1987), although McCune and Mefford (1997) state that ‘the consequences of the choice of local vs. global NMS have not been fully explored in the literature’.

Non-metric multi-dimensional scaling ‘is an iterative search for a ranking and placement of n entities on k dimensions (axes) that minimises the stress of the *k*-dimensional configuration’ (McCune and Mefford 1999). The ordination is based on a dissimilarity matrix that is calculated from the matrix of sites-by-species (i.e. the vegetation data). The NMS program calculates the minimum ‘stress’ in each of 6 dimensions. ‘Stress’ ‘is a measure of the departure from monotonicity in the relationship between the dissimilarity (distance) in the original p-dimensional space [where p is the number of species in the vegetation data] and distance in the reduced k-dimensional space' (McCune and Mefford 1999). To determine the final dimensionality of any given data set, a stress plot, showing the stress for the 1 through 6 dimensional results is produced. Typically the stress is reduced as each successive dimension is added, although the reduction is variable. The NMS program adopts for final use that ordination which achieves no further significant reduction in stress through the addition of further dimensions (defined within PC-ORD as a decrease in stress of 5 on a 100 point scale).

PC-ORD offers a choice of dissimilarity coefficients for use in the ordination. Faith *et al.* (1987) examined the usefulness of a number of dissimilarity coefficients and found that the Bray-Curtis coefficient was among the 'most effective and robust of the measures compared'. The Bray-Curtis coefficient was consequently used for all the analyses presented here. PC-ORD also offers the choice of three 'thoroughness' settings; the fastest computationally is 'quick and dirty', wherein the maximum number of iterations is limited to 75, the instability criterion is set to 0.001, the starting number of axes (i.e. the number of dimensions which are explored by the analysis) is limited to 3, and 5 runs are completed with the real data and 20 with randomised data (in order to compare differing results). The slowest option computationally is the 'slow and thorough' wherein there are 400 iterations, the instability criterion is set to 0.00001, the starting number of axes (i.e. the number of dimensions which are explored by the analysis) is raised to 6, and 40 runs are completed with the real data and 50 with randomised data. A medium setting lies between these two (McCune and Mefford 1999). For exploratory purposes in this study, the 'quick and dirty' settings were used, then for the final analysis (i.e. once any errors in the data had been corrected) the 'slow and thorough' settings were applied.

The ordination provided by NMS was analysed by correlation analysis of the sample variables (slope, aspect, altitude, fire history and for the subset analysis only, drainage) against the ordination scores of the quadrats.

The results of the TWINSPAN analysis were overlaid on the results of the NMS in order to determine the spread of the quadrats through the environmental space and to examine the clustering of the quadrats in order to determine the point at which it was reasonable to stop the TWINSPAN division. Uncontrolled, TWINSPAN will keep dividing each group until there are less than a pre-determined and arbitrary number of quadrats in each group. In this study, the division was stopped at the four group level, and the relationship between the groups was examined using multi-response permutation procedure (MRPP), which tests the hypothesis of no difference between the groups.

As an additional test of the groups produced through TWINSPAN and NMS, cluster analysis was used to produce a hierarchical, agglomerative and polythetic dendrogram of the quadrats. The location of each of the quadrats from the control plots was highlighted on the scatterplot of the quadrats to examine whether the control plots were representative of the vegetation of the SST. The results of the cluster analysis were compared manually to the preliminary classification of the quadrats.

Results

Ordination

The DCA ordination and the two NMS ordinations were very similar in their final result and therefore only one is shown (the second NMS, Figure 3.2). The only difference between the DCA ordination and the random start NMS ordination lay in the orientation of the output – the relationships between the points was the same (i.e. the NMS (1) ordination was the same as the DCA ordination except that

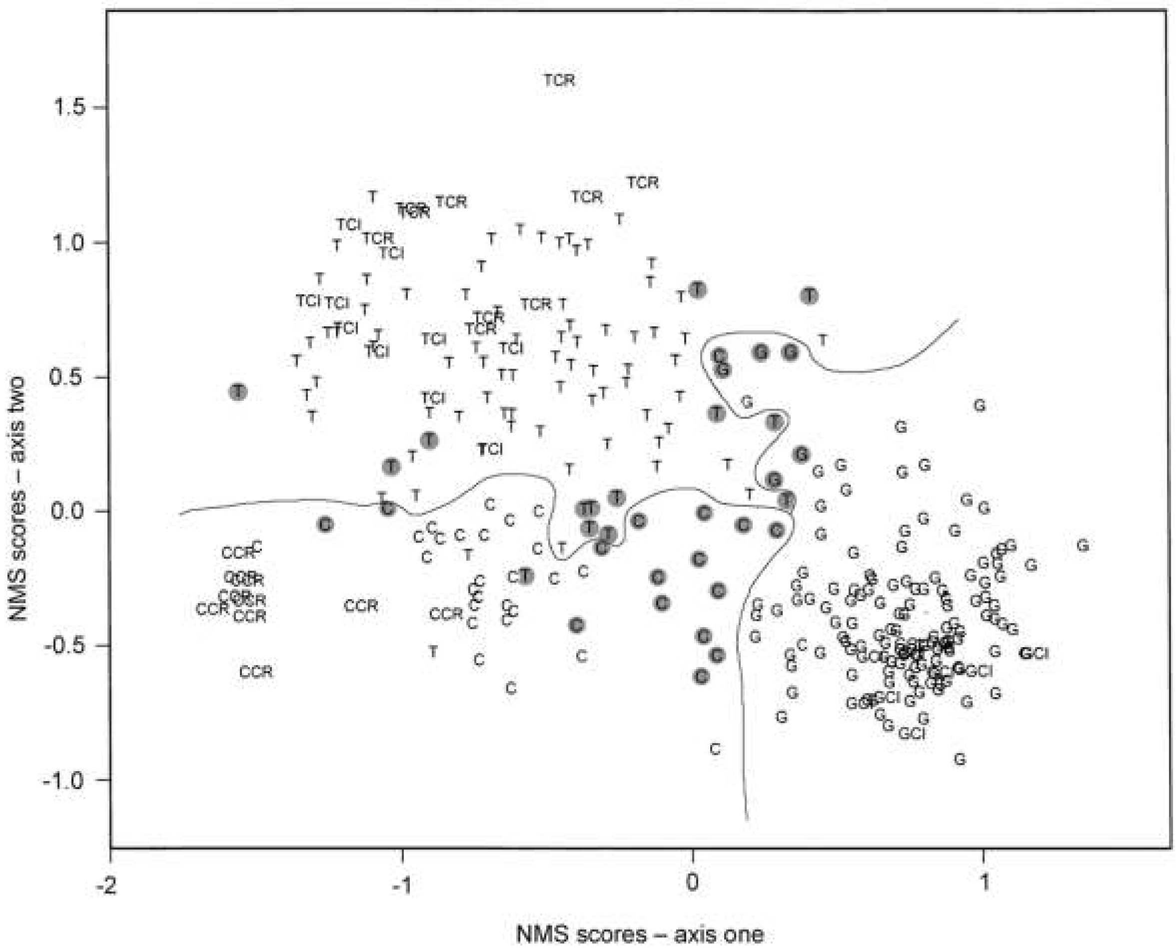


Figure 3.2. NMS ordination of the quadrats. Codes G, C and T as described in the text. The points are labelled G, C or T according to their classification by the cluster analysis. The control plots are labelled: TCR = T control external, TCI = T control internal, CCR = C control external, GCI = G control internal. The shaded quadrats are

those which were classified differently by the cluster analysis and ordination described above, as compared to the preliminary classification. The lines separate the three floristic types.

it was rotated about 60 degrees). The NMS (2) ordination, which used the DCA output as a starting configuration, was almost identical to that produced by DCA. There was a significant reduction in stress between the one dimensional (24) and two-dimensional (16) results but little additional reduction in stress in 3 dimensions (12) which suggests that the data are two-dimensional. The two-dimensional ordination is shown.

The dendrogram produced by the cluster analysis clustered the quadrats into three groups. The three groups are overlaid on the ordination diagram.

Fire history was the only sample variable found to be significantly correlated to the ordination ($r^2 = 0.681$). The subset analysis (not shown) which included the drainage sample variable also found fire history to be the only significantly related variable.

TWINSPAN

The first division of the TWINSPAN classification separated rainforest understorey types, characterised by the presence of *Eucryphia lucida* and *Atherosperma moschatum,* from wet sclerophyll understorey types, characterised by the presence of *Bauera rubioides, Nematolepis squamea* and *Leptospermum lanigerum*. A second division separated the rainforest quadrats into thamnic and callidendrous understorey types. The thamnic types were characterised by the presence of *Anodopetalum biglandulosum* and *Cenarrhenes nitida*, whilst the callidendrous types were characterised by the presence of *Dicksonia antarctica, Histiopteris incisa* and *Hymenophyllum flabellifolium*. These two groups were readily recognisable in the forest and so this division was accepted. A second division of the wet sclerophyll understorey types, separated quadrats which contained scattered individuals of species more typical of later successional forests (*Phyllocladus aspleniifolius, Grammitis billardierei, Hymenophyllum rarum* and *H. peltatum*) from those which lacked such species. The projective foliage cover of these species was rarely greater than 1% and the common and frequent species within both these groups were the same. The different types were not readily recognisable in the forest. Consequently the second division of the wet sclerophyll understorey types was rejected.

Multi-response permutation procedure

The multi-response permutation procedure tests the hypothesis that there was no difference between the groups identified by the TWINSPAN analysis. The test rejected the hypothesis and showed that the difference between the groups was highly significant ($p < 0.0001$).

Comparison of classifications

The shaded quadrats in Figure 3.2 are those which were classified differently by the cluster analysis and ordination described above, as compared to the preliminary classification. It is evident from the figure that all the quadrats which were misclassified were those which lay close to the boundaries of the three groups. As noted above, species more typical of later successional forests are present as scattered individuals in some of the sclerophyll quadrats – such quadrats are inevitably more difficult to assign to one group or another, and all are placed close to the line separating the two groups. Similarly the division between callidendrous and thamnic quadrats is sometimes, but not always, clearly apparent in the forest. In reality there is a continuum from clearly callidendrous type quadrats, to clearly thamnic type quadrats, and there will always be those in the middle that are difficult to classify, and that are classified inconsistently from one procedure to another.

Discussion

The ordination and classification procedures, in combination with the multi-response permutation procedure and the cluster analysis, show strong support for the preliminary qualitative classification of the vegetation. The three identified groups were clearly separated by the ordination, albeit with a zone of overlap. Importantly, these groups are usually easily recognisable in the field, although there can be difficulties in allocating quadrats to either thamnic or callidendrous rainforest, as reflected in the ordination diagram, where such quadrats were sometimes misclassified. Control plot quadrats encompass the full environmental space covered by the vegetation of the SST (Figure 3.2). Any change that results from external influences such as climate change will be reflected by changes in the location of control plots in the ordination space. Changes in the vegetation that are brought about by the harvesting operations will be discernible as changes in location of treatment quadrats in the ordination space relative to the controls.

The correlation analysis of the site variables against the ordination scores indicates that the vegetation within the Warra SST is strongly influenced by the local fire history of each site. Fire behaviour in turn is influenced by local topography and this is reflected in the vegetation (Hickey *et al.* 1999). Below Manuka Rd (Figure 3.1) wet sclerophyll species dominate the understorey vegetation except along the major drainage lines where rainforest elements predominate. Above Manuka Road, wet sclerophyll understoreys dominate the flatter areas and rainforest understoreys extend along the major drainage lines and the steeper south facing slopes which run across the middle of WR8H and WR8B. In Warra 1A, rainforest understoreys are restricted to the steeper slopes and the lower gentler slopes are again dominated by wet sclerophyll understoreys.

Appendix 3.1. The vegetation communities.

Note that only the dominant and principal understorey species are listed below. See Table 3.1 for the full species list for each community.

G type

Eucalyptus obliqua wet sclerophyll forests over tall *Leptospermum lanigerum – Melaleuca squarrosa* swamp forest (*sensu* Corbett and Balmer (2001)). This community is closely related to OB3, *Eucalyptus obliqua – Phebalium squameum(= Nematolepis squamea) – Bauera rubioides* wet sclerophyll forest *sensu* Duncan and Johnson 1995).

Trees: *Eucalyptus obliqua.*
Shrubs: *Leptospermum lanigerum, Melaleuca squarrosa, Nematolepis squamea, Acacia verticillata, Bauera rubioides.*
Ferns: *Blechnum wattsii, Gleichenia microphylla*.
Graminoids: *Gahnia grandis*.

This community is the most homogenous of the forest types within the SST and is widespread. It occupies most of the lower gentle slopes and flats. Four of the eight coupes (8C, 8I, 1E and 1B) within the SST comprise only this forest type. The *E. obliqua* overstorey is a mixture of oldgrowth and regrowth arising from past fires with a mean top height of about 45 m. The understorey is about 10 m tall and varies from an open shrub layer to closed thickets. It is dominated by *L. lanigerum* and *M. squarrosa*, with *N. squamea* and *A. verticillata* widespread but less common. *Gahnia grandis* and *Bauera rubioides* are ubiquitous, forming a closed ground layer except where the tea-tree and paperbark understorey forms a closed secondary canopy and light levels beneath this are low enough to control the spread of *Gahnia* and *Bauera*. *Blechnum wattsii* (hard water fern) is found throughout the community as small clumps but doesn't form the dense thickets characteristic of some rainforests.

T type

Eucalyptus obliqua over thamnic rainforest (*sensu* Jarman *et al.* 1984), (this community is closely related to OB1001, Kirkpatrick *et al.* 1988).

Trees: *Eucalyptus obliqua, Eucryphia lucida, Phyllocladus aspleniifolius, Nothofagus cunninghamii, Atherosperma moschatum, Acacia melanoxylon.*
Shrubs: *Cenarrhenes nitida, Anodopetalum biglandulosum, Anopterus glandulosus.*
Ferns: *Blechnum wattsii, Grammitis billardierei, Hymenophyllum rarum, Grammitis magellanica* subsp. *nothofageti.*
Graminoids: *Gahnia grandis*.

This is the dominant mixed forest community within the SST. The structure is highly variable, ranging from dense thickets of horizontal with few other species present, to more broken forest with a high species diversity and a variable structure.

C type

Eucalyptus obliqua over callidendrous rainforest (*sensu* Jarman *et al.* 1984), (this community is closely related to OB1000, Kirkpatrick *et al.* 1988).

Trees: *Eucalyptus obliqua, Nothofagus cunninghamii, Phyllocladus aspleniifolius, Eucryphia lucida, Acacia melanoxylon, Atherosperma moschatum*.
Shrubs: *Acacia verticillata*.
Ferns: *Polystichum proliferum, Hymenophyllum flabellatum, Blechnum wattsii, Histiopteris incisa, Dicksonia antarctica, Grammitis billardierei, Hymenophyllum cupressiforme, Hymenophyllum rarum.*
Graminoids: *Gahnia grandis*.

Mixed forest with a callidendrous rainforest understorey occurs only in local patches within the Warra SST. It is most common in Warra 1A, on the better drained soils which have developed on the Permian sediments. The eucalypts in Warra 1A are also consistently taller and of better form than those in the rest of the SST. Rainforest species trees which probably arose following the last wildfire in 1934 (Hickey *et al.* 1999) form a small (15 to 20 m tall) tree layer over an understorey dominated by ferns.

Appendix 3.2. Vegetation of the Warra SST showing species abundance by vegetation type.

		Vegetation type		
		C	T	G
Ferns and Fern Allies				
Aspleniaceae	*Asplenium appendiculatum*	r	r	–
Blechnaceae	*Blechnum nudum*	r	r	r
	Blechnum wattsii	c	c	c
Dennstaedtiaceae	*Histiopteris incisa*	c	o	o
	Hypolepis rugosula	r	r	–
	Pteridium esculentum	r	r	o
Dicksoniaceae	*Dicksonia antarctica*	c	o	o
Dryopteridaceae	*Polystichum proliferum*	o	–	r
	Rumohra adiantiformis	o	o	r
Gleicheniaceae	*Gleichenia microphylla*	–	r	c
	Sticherus tener form B	–	r	r
Grammitidaceae	*Ctenopteris heterophylla*	o	o	r
	Grammitis billardierei	c	c	o
	Grammitis magellanica subsp. *nothofageti*	o	c	r
	Grammitis pseudociliata	o	o	–
Hymenophyllaceae	*Hymenophyllum australe*	o	o	r
	Hymenophyllum cupressiforme	c	o	o
	Hymenophyllum flabellatum	c	o	o
	Hymenophyllum marginatum	r	o	r
	Hymenophyllum peltatum	o	o	o
	Hymenophyllum rarum	c	c	o
	Crepidomanes venosum	o	–	–
Polypodiaceae	*Microsorum pustulatum*	o	o	r
Psilotaceae	*Tmesipteris elongata*	r	–	–
	Tmesipteris obliqua	o	o	r
Conifers				
Podocarpaceae	*Phyllocladus aspleniifolius*	c	c	o
Flowering Plants				
Dicotyledons				
Asteraceae	*Olearia argophylla*	r	–	r
	Olearia persoonioides	–	r	–
Cunoniaceae	*Anodopetalum biglandulosum*	o	c	r
	Bauera rubioides	–	o	c

– not recorded from that vegetation type
r = rare – found in less than 5% of plots in that vegetation type
o = occasional – found in 5 to 50% of plots in that vegetation type
c = common – found in more than 50% of plots in that vegetation type

Appendix 3.2. (cont) Vegetation of the Warra SST showing species abundance by vegetation type.

		Vegetation type		
		C	T	G
Dilleniaceae	*Hibbertia empetrifolia*	r	–	o
Elaeocarpaceae	*Aristotelia peduncularis*	r	o	o
Epacridaceae	*Cyathodes glauca*	o	o	o
	Epacris impressa	–	–	r
	Leptecophylla juniperina	–	r	r
	Monotoca glauca	o	o	o
	Prionotes cerinthoides	o	–	o
	Trochocarpa cunninghamii	–	o	r
	Trochocarpa gunnii	–	r	–
Escalloniaceae	*Anopterus glandulosus*	r	o	r
Eucryphiaceae	*Eucryphia lucida*	c	c	o
Fabaceae	*Pultenaea juniperina*	–	–	r
Fagaceae	*Nothofagus cunninghamii*	c	c	o
Haloragaceae	*Gonocarpus teucrioides*	–	–	o
Mimosaceae	*Acacia melanoxylon*	c	c	r
	Acacia mucronata	–	–	r
	Acacia verniciflua	–	–	r
	Acacia verticillata	c	o	c
Monimiaceae	*Atherosperma moschatum*	c	c	r
Myrtaceae	*Eucalyptus delegatensis*	–	r	r
	Eucalyptus obliqua	c	c	c
	Leptospermum glaucescens	–	–	r
	Leptospermum lanigerum	r	r	c
	Leptospermum scoparium	–	–	o
	Melaleuca squamea	–	–	r
	Melaleuca squarrosa	o	r	c
Oleaceae	*Notelaea ligustrina*	–	–	r
Pittosporaceae	*Billardiera longiflora*	–	–	r
	Pittosporum bicolor	o	o	r
Proteaceae	*Banksia marginata*	–	–	o
	Cenarrhenes nitida	o	c	o
	Lomatia polymorpha	–	–	r
	Orites diversifolia	–	r	–
	Telopea truncata	–	–	r

– not recorded from that vegetation type
r = rare – found in less than 5% of plots in that vegetation type
o = occasional – found in 5 to 50% of plots in that vegetation type
c = common – found in more than 50% of plots in that vegetation type

Appendix 3.2. (cont) Vegetation of the Warra SST showing species abundance by vegetation type.

		Vegetation type		
		C	T	G
Ranunculaceae	*Clematis aristata*	o	o	o
Rhamnaceae	*Pomaderris apetala*	o	o	o
	Pomaderris elliptica	–	–	r
Rubiaceae	*Coprosma nitida*	–	r	r
	Coprosma quadrifida	o	o	o
	Galium australe	r	r	o
Rutaceae	*Correa lawrenceana*	–	r	o
	Nematolepis squamea	o	o	c
Thymelaeaceae	*Pimelea cinerea*	–	r	–
	Pimelea drupacea	o	o	o
	Pimelea sericea	–	–	r
Violaceae	*Viola hederacea*	–	–	r
Winteraceae	*Tasmannia lanceolata*	o	o	o
Flowering Plants				
Monocotyledons				
Cyperaceae	*Baumea tetragona*	–	–	r
	Gahnia grandis	c	c	c
	Isolepis spp.	–	–	r
	Lepidosperma ensiforme	–	–	o
	Schoenus apogon	–	–	r
Liliaceae	*Drymophila cyanocarpa*	r	o	o
Orchidaceae	*Corybas* spp.	–	r	r
	Pterostylis spp.	–	–	o
Restionaceae	*Baloskion tetraphyllus*	–	–	r
	Calorophus elongatus	–	–	o

– not recorded from that vegetation type
r = rare – found in less than 5% of plots in that vegetation type
o = occasional – found in 5 to 50% of plots in that vegetation type
c = common – found in more than 50% of plots in that vegetation type

Chapter 4. The impact of the harvesting and burning disturbances on the vegetation

Introduction

Changing public policy, both here in Tasmania (Commonwealth of Australia and State of Tasmania (1997, 2005) and elsewhere in the world (e.g. the USA, (Franklin *et al.* 1997, 1999), Canada (Arnott and Beese 1997), South America (Martinez Pastur *et al.* 2007) and Europe (Fries *et al.* 1997) has driven a shift away from traditional clearfelling methods of harvesting temperate wet forests and towards alternative methods which generally include retention of some portion of the pre-harvest stand. The fundamental premise is that it is more ecologically valuable to retain structural and floristic elements within the regenerating stand, rather than around it, or elsewhere in the landscape (Franklin *et al.* 1997; Halpern *et al.* 1999; Forestry Tasmania 2009b). Franklin *et al.* (1997) have reviewed the benefits of structural retention, but there has been less work on the floristic benefits, partly because of the limited amount of time that has elapsed since variable retention harvests have been completed. The longest running study, the DEMO trial in the Pacific Northwest, was established in the mid-1990s so the results emerging now (Halpern *et al.* 2005; Nelson and Halpern 2005; Aubry *et al.* 2009) are based on less than 10 years of post disturbance response.

In developing the clearfell burn and sow (CBS) silvicultural system, its proponents argued that CBS best mimicked the natural disturbance dynamic, whereby abundant regeneration typically follows a wildfire (Gilbert and Cunningham 1972; Attiwill 1994). Critics point to a number of differences between CBS and wildfires. Amongst other things, for example differing fire intensities and levels of soil disturbance, the patterns and composition of the floristic recovery following CBS may be different to that following a wildfire (Dickinson and Kirkpatrick 1987; Ough 2001; Lindenmayer and McCarthy 2002).

A number of authors have examined the early patterns of recovery of wet forest understorey vegetation in south-eastern Australia following disturbance either by CBS or wildfire or by comparing both (Cremer and Mount 1965; Cook and Drinnan 1984; Mueck and Peacock 1992; Ough and Ross 1992; Peacock 1994; Chesterfield 1996). These studies have shown that the majority of the species present pre-disturbance regenerate post-disturbance but that their relative abundances may differ. Many late successional species like epiphytic ferns and rainforest trees tend to be at lower frequencies and/or abundances in silvicultural than wildfire regeneration (Hickey 1994; Ough 2001). Clearfelling can negatively affect species that may rely primarily on vegetative resprouting for regeneration such as tree ferns (Ough and Murphy 2004), although other studies have shown that many tree ferns survive CBS (Peacock 1994). Ground-based harvesting can have significant impacts on the soil (Rab 1994; Rab 1996), and can physically disturb the lignotubers and rhizomes which many species rely on for regeneration (Ough and Ross 1992; Ough 2001).

Ough (2001) compared the floristics of regenerating stands six to fourteen years after CBS treatments, with the floristics of regenerating stands ten years after a wildfire. She found that *Acacia dealbata* (silver wattle), sedge and weed species were relatively more abundant in silvicultural (clearfell-origin) regeneration than in wildfire regeneration, whereas vegetatively resprouting shrubs, tree-ferns and ground ferns were more abundant in the wildfire regeneration. Ough (2001) suggested that the different initial floristic and structural composition of the silvicultural regeneration early in the rotation meant that it may never recover similar composition to that of wildfire regeneration. In a contrasting before-and-after study at two CBS sites in the Otway Ranges in Victoria, Harris (2004) found weed species to be briefly abundant in the early successional stage, but to be insignificant 16-17 years post-harvesting. At this stage some epiphytic ferns had re-established and understorey shrubs and trees present pre-harvesting were all recovering, either from seed or vegetatively.

Hickey (1994) compared 20-to-30 year old silvicultural and wildfire regeneration in Tasmania. Like Ough (2001), he also found an increased abundance of sedges and a lower frequency of epiphytic ferns in silvicultural compared to wildfire regeneration. However Hickey considered that the species composition of silvicultural regeneration was sufficiently similar to that of wildfire regeneration to indicate that, in the absence of further disturbance, the silvicultural regeneration could progress to become mixed forest and eventually even rainforest. Notably, whilst Hickey (1994) looked at older regeneration than any other study, it was still younger than the planned rotation age of about 90 years (Whiteley 1999).

Longer periods are clearly required for late successional species to fully redevelop in silvicultural regeneration, and typical planned rotation lengths of about 90 years may not be sufficient to allow their return to pre-disturbance abundance and diversity. Repeated CBS rotations of such length may cause a reduction in the abundance of late-successional species (Hickey 1994; Ough and Murphy 1996; Lindenmayer and McCarthy 2002), and a decline in the special (rainforest) species timber resource (Hickey *et al.* 2006).

These factors were all considered when developing the range of treatments to be included in the Warra silvicultural systems trial (SST) (Hickey *et al.* 2001). All of the treatments established were designed to retain elements from the pre-harvest stand into the regenerating stand, in order to both maintain floristic and structural diversity within the harvested stand, and to facilitate the more rapid re-establishment of later successional species into the regenerating stand than would be the case following a clearfell.

To examine whether these aims could be met, the objectives of this study were to assess: (a) the response of the vegetation at the Warra SST to the disturbance caused by the harvesting and the burning where applied, and (b) whether there were significant differences between the silvicultural systems with respect to their impact on the vegetation.

Methods

Plot re-measurement

The floristic quadrats were established as described in the previous chapter. Prior to any disturbance, data were collected from each quadrat on the projective foliage cover of each higher plant species present using a modified Braun – Blanquet scale (Mueller-Dombois and Ellenberg 1974) (1 = 0 to 1%, 2 = 2 to 5%, 3 = 6 to 25%, 4 = 26 to 50%, 5 = 51 to 75% and 6 = 76 to 100%) and the projected foliage cover (%) of each layer of the vegetation. The same observer conducted all the assessments.

At the completion of harvesting and regeneration burning, where applied, of each coupe, all the vegetation quadrats located in and immediately around that coupe were relocated and visually surveyed for the impact of the harvesting and burning. Each quadrat was allocated to one of three impact classes:

- **disturbed**; where the quadrat lay predominantly within the harvested area of a coupe and where the original vegetation had been largely or completely removed by the harvesting disturbance and/or burning;
- **exposed**, where the quadrat lay predominantly within up to 10 m of a harvested edge but had not otherwise been significantly impacted by the harvesting and burning disturbance; and
- **undisturbed**, where the quadrat lay predominantly more than 10 m from a harvested edge. Westphalen (2003) has shown that the 'edge effect' in these forests, in terms of altered microclimate and light regimes, extends only about 10 m from the edge of the harvested area into the adjacent unharvested forest.

The impact of the harvesting and burning on the soil within each of the disturbed vegetation quadrats in each coupe was assessed, and the impacts classified as shown in Table 4.1. The burning and disturbance impacts on the soil are not independent. Where the soil was burnt to mineral soil (BM) or burnt to ash-bed (B2), it was not considered possible to determine a disturbance class since partial or complete oxidation altered the soil beyond the point to which disturbance could be reliably recognised. This assessment determined the proportion of each seedbed class found within each quadrat.

Table 4.1. Seedbed burn and disturbance classes.

<u>Burn classes</u>

B0	Unburnt (or burnt so lightly as to not affect the seedbed)
BL	Burnt but unburnt litter still present (minor soil heating but soil often not exposed)
BM	Burnt to mineral soil (charcoal present over exposed and heated mineral soil)
B2	Ashbed (intense soil heating, soil oxidation)

<u>Disturbance classes</u>

D0	Undisturbed
D1	Revealed (litter removed from mineral soil or soil disturbed and aerated)
D2	Compacted (litter removed and soil compacted, generally from machinery movement)

<u>Seedbed classes</u>

	D0	D1	D2
B0	1	2	3
BL	4	5	n/a
BM		6	
B2		7	

The first winter (June) following the completion of the harvesting, and burning where applied, was deemed to be the birthday of the coupe, that is, age zero years. There is generally little response from the vegetation between the time of the regeneration burn and the first winter, with the majority of the post-disturbance vegetation recovery first evident in the following spring, hence the first winter is an appropriate time to 'start the clock'.

The impact of the harvesting and burning on the vegetation within each of the disturbed quadrats was examined immediately after completion of these operations i.e. at age zero years. There was no intact vegetation on any of the disturbed quadrats at this time. Only the quadrats in the understorey islands and their associated controls were remeasured at age one year. All the disturbed and exposed quadrats were remeasured at age three years, and where possible, depending on the harvesting time of each coupe within the trial, at age six years. The control quadrats were remeasured ten years after commencement of the trial. As the three different floristic types (G, C and T) were unevenly distributed across the trial, and as the coupes were established over a nine-year period, not all the floristic types were sampled evenly through time. For example, the two CBS with understorey island coupes (WR8B and WR8H) contained G and T types prior to harvesting, and these were resampled one year after harvesting, but contained no C-type quadrats, hence there was no sampling of C type at age one year. All the remeasurements of the quadrats were done 'blind', that is, without comparison to the previous record from that quadrat. The number of plots of each type sampled at each time is summarised in Table 4.1b.

Table 4.1b. The number of quadrats of each floristic type sampled at each sampling time.

	Sampling time					
Plot type	Pre-harvest	Post harvest	Age 1 yr	Age 3 yr	Age 6 yr	Age 10 yr
G disturbed	87	87	32	84	37	-
G exposed	12	12	13	13	13	-
G control	24	-	1*	1*	2*	20
T disturbed	20	20	9	17	13	-
T exposed	19	19	11	11	9	-
T undist'd	19	-	1*	12	2*	-
T control	20	-	-	-	-	20
C disturbed	39	39	-	39	10	-
C exposed	6	6	-	-	6	-
C control	11	-	-	-	-	10

Note . The quadrats marked #* lie within otherwise harvested areas that remained undisturbed during the course of harvesting. These quadrats are shown in Figures 4.1a and 4.1b but are not included in the summary tables.

The undisturbed quadrats served as additional control locations. Amongst the G- and C-type quadrats there was only one or two quadrats remained undisturbed, so these quadrats have been combined with the control quadrats in the ordinations and summary tables. For T type quadrats there were 19 quadrats that were undisturbed so these were retained as a separate data set; these quadrats were measured at establishment and at age one (one quadrat only), three (12) and six years (2).

Analysis

NMS Ordination

Analysis of the vegetation quadrat data was undertaken using PC-ORD (McCune and Mefford 1999) and Statgraphics (Statistical Graphics Corporation 1994-1996). The data were ordinated using non-metric multi-dimensional scaling (NMS). Owing to the large size of the final data set (644 quadrats including remeasurements) the final ordination was difficult to interpret visually. To simplify the presentation, the centroid of the set of quadrats within each vegetation type by each disturbance class at each measurement age, and the centroid of each control set prior to the commencement of harvesting and 10 years later, was calculated using Euclidean geometry. The change in distance in the three-dimensional ordination space for the disturbed quadrats from their position in the ordination space at time pre-harvest to their position in the ordination space at age six years, was regressed against the variables derived from the seedbed assessments to determine whether the change could be related to the intensity and impacts of the harvesting and burning. As not all of the treatments had yet reached six years of age, not all of the quadrats within the study were available for this analysis. This analysis was undertaken only for the changes in distance in the ordination space from time pre-harvest to age six years in the belief that the one- and three-year vegetation response was not as representative as the longer term, six-year response. The change in distance in the ordination space for the same set of quadrats as above was also regressed against the silvicultural system to determine whether the change could be related to silvicultural system.

Quadrat summary tables

The tables that follow (Tables 4.2 to 4.11) were prepared to clarify the underlying floristic changes that have caused the changes in location of the quadrats within the ordination space. Summary tables of the vegetation data were prepared showing the mean Braun-Blanquet score (Mueller-Dombois and Ellenberg 1974) and the percentage frequency of occurrence for each species within each vegetation type by each disturbance class at each measurement age. Species names in the tables are abbreviated to an eight character code comprising the first four characters of the genus and the first four characters of the species. The full species names are listed in Appendix 4.1.

To aid interpretation of the data within each table, the species were manually sorted into five groups representing different post-disturbance responses. Not all five groups are present in all the tables. Rarer species (as noted in each table) have not been included.

The five groups are:

Group one: Species whose cover and/or frequency remained relatively constant over the sampling period, or where the species was recorded too rarely to confidently ascribe a trend.

Group two: Species whose cover and/or frequency rapidly increased from a low level pre-harvest to a higher level by age 1 year or age 3 years and then rapidly decreased again.

Group three: Species whose cover and/or frequency rapidly increased from a low level pre-harvest to a higher level by age 1 year or age 3 years and that maintained that level to age 6 years.

Group four: Species whose cover and/or frequency rapidly decreased from pre-harvest levels but that have persisted at lower levels of abundance compared to pre-harvesting.

Group five: Species whose cover and/or frequency rapidly decreased from pre-harvest levels and that remain absent or sparse at ages 1, 3 and 6 years. Where there was a large number of species in Group five it was further sub-divided into two sub-groups; the first sub-group is shrubs and orchids, the second is ferns.

The allocation of each species to a particular group within each table was based on the change in the frequency of each species over the sampling period. The statistical significance of the difference was determined using the one-proportion z test (Peatman 1962). The test was applied to the difference in the frequency of each species between time pre-harvest and age six years except for Group two where it was applied to the difference in the frequency of each species between time pre-harvest and age three years. This was done because Group two species had typically come and gone by age six years. Values of zero (0%) and one (100%) cannot be handled by the test as they lead to a zero divisor; zeros were given a frequency of 1% and 'ones' a frequency of 99%. When the frequency pre-harvest and at age three or six years is the same, the statistic cannot be calculated as the change in proportion is zero; clearly in such instances there has been no change. Where the number of quadrats for any particular group is low (less than about 12 quadrats) variation in frequency can be strongly influenced by a small variation in occurrence of that species so the results need to be viewed with caution. Where there was any doubt as to the biological significance of the difference, or where the species was rare in relation to the overall abundances within the set of quadrats, the species was retained in Group one. Within each group the species are listed in decreasing order of total mean cover.

The vagaries of the sampling meant that in some cases, there were only one or two quadrats recorded within a particular set at a particular time. For example, only one undisturbed T-type quadrat was remeasured at age one year. Such instances have not been included in the summary tables; a single occurrence of a species when only one quadrat has been sampled returns a frequency of 100%. This can be very misleading when comparing the results to sets of more than 80 quadrats.

The data from age one-year, where present, must be interpreted with caution and in the context of the data from pre-harvest and age three and six years. At age one year many species were only just appearing or re-appearing on the quadrats. Many species that were infrequent prior to harvest were apparently absent at the age one-year remeasurement but had reached similar levels to pre-harvest by age three or six years.

The average species richness was calculated for each set of quadrats within each vegetation type by each disturbance class at each measurement age, given that there were at least three quadrats within that set.

Results

Ordination

There was a significant reduction in stress from the one dimensional (48) to the two-dimensional (29) and again to the three-dimensional result (14) but the stress in four dimensions (17) increased compared to the three-dimensional result, which indicates that the data are three-dimensional. The ordination is shown in Figure 4.1a and b. Note that the ordination shows all the quadrat groups, even those that represent only a small number of quadrats, as indicated in Figure 4.1a by superscripts. Changes in the ordination space for groups that comprise fewer than 5 quadrats must be interpreted with caution. Such groups have not been included in the summary tables.

The control plots did not shift significantly in the ordination space over the sampling period, particularly compared to the shift in the ordination space of sets of quadrats that were disturbed by the harvesting. The centroids of the disturbed and exposed G-type quadrats at age one year shifted well away from the centroids of the undisturbed and control quadrats pre-harvest. The centroids of the disturbed and exposed G-type quadrats at age three years have shifted closer to the undisturbed quadrats and by age six years they have shifted closer again.

Conversely, the centroids of the disturbed rainforest understorey types (T and C) by age three years shifted towards the area in the ordination space dominated by the G-type quadrats and by age 6 years shifted a little further towards that area. The vegetation of these quadrats has shifted away from rainforest species and towards species that are more typical of wet eucalypt forests. The centroids of the exposed T-type quadrats at ages three and six years also shifted towards the ordination space dominated by the G-type quadrats. The exposed C-type quadrats by age six years were in a very similar space as pre-harvest (Figure 4.1a. and 4.1b, i.e. in all axes of the ordination space), yet from the summary tables it is clear that there have been some changes in the vegetation of these quadrats. The actual changes in the species composition, cover-abundance and frequency in the various sets of quadrats is discussed in more detail below under ‘quadrat summary tables’.

No statistically significant relationship could be discerned between the change in distance in the three-dimensional ordination space for the disturbed quadrats at age six years and either the seedbed variables or the silvicultural system.

Quadrat summary tables

G-type disturbed

Disturbed G-type quadrats were distributed throughout the trial except for the two group selection coupes (WR5D and WR8G). The uniformity of the vegetation response within this set is indicated by the very high frequencies in Table 4.2 for the dominant species; the same small suite of species dominate most of the disturbed G-type quadrats.

All of the relatively common species present pre-disturbance, that is those with a mean cover of greater than 1 (Braun-Blanquet scale, (Mueller-Dombois and Ellenberg 1974)), regenerated strongly post-disturbance (Group 1 in Table 4.2). The dominant overstorey species in the regenerating vegetation is *Eucalyptus obliqua*. *Eucalyptus obliqua* seed was oversown on the two CBS with understorey island

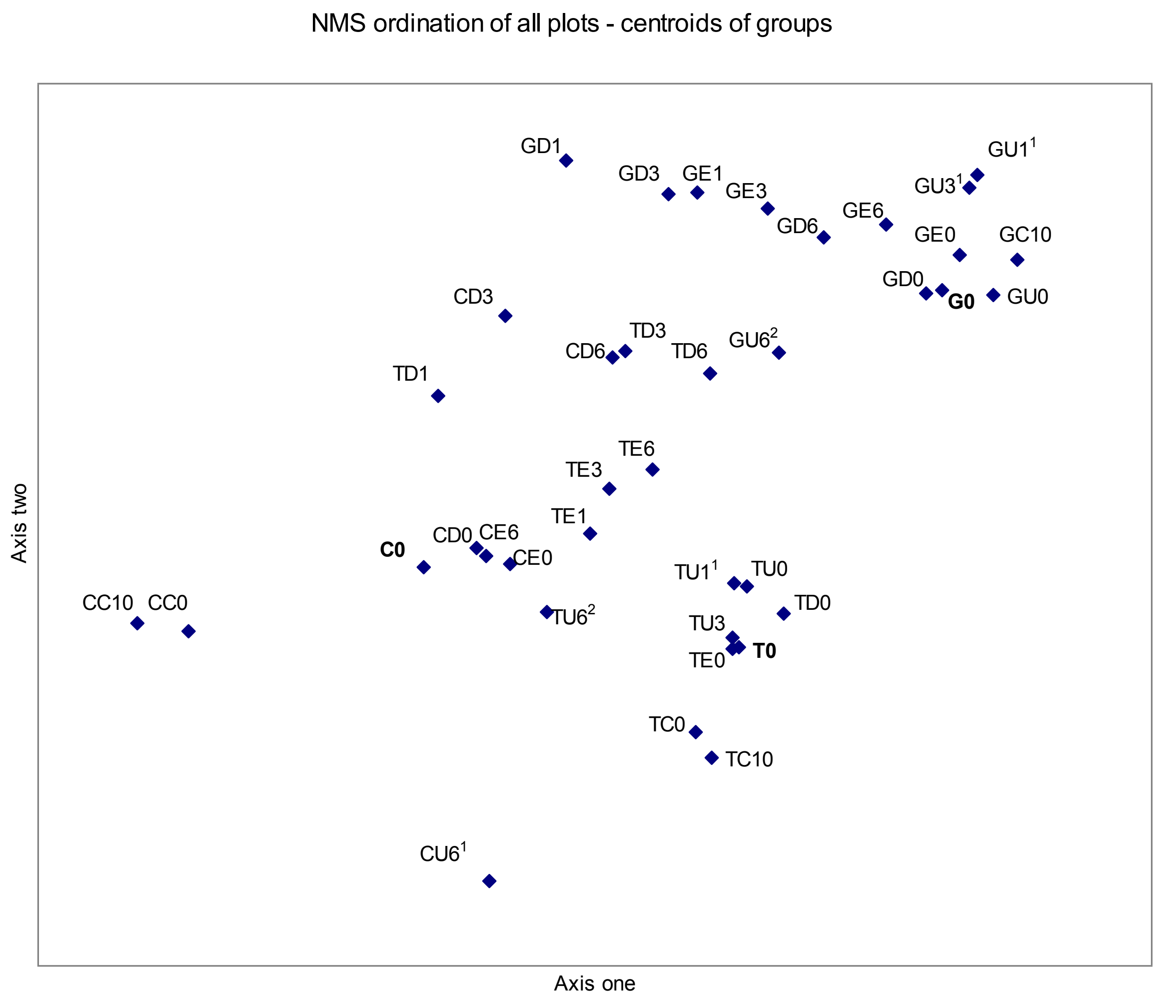


Figure 4.1a. Non-metric multi-dimensional scaling (NMS) ordination, axis one versus axis two, of all the vegetation quadrats showing centroids of all the sets.

The first character of each label is the understorey vegetation type; G = *Gahnia* type, T = thamnic rainforest type, C = callidendrous rainforest type. The second character of each label is the impact class of that set; D = disturbed, E = exposed, U = undisturbed, C = control. The numbers indicate the age at sampling; 0 = pre-harvest, otherwise in years. Superscripts indicate centroids that are derived from only the number of quadrats indicated by the superscript; for example CU6^1 is the centroid of the lone callidendrous undisturbed quadrat sampled at age 6 years. The number of quadrats sampled in the unmarked quadrats is shown in the summary tables (Tables 4.2 to 4.11). The points **G0**, **T0** and **C0** represent the centroid of all the quadrats within that vegetation type from time 0 (pre-harvest).

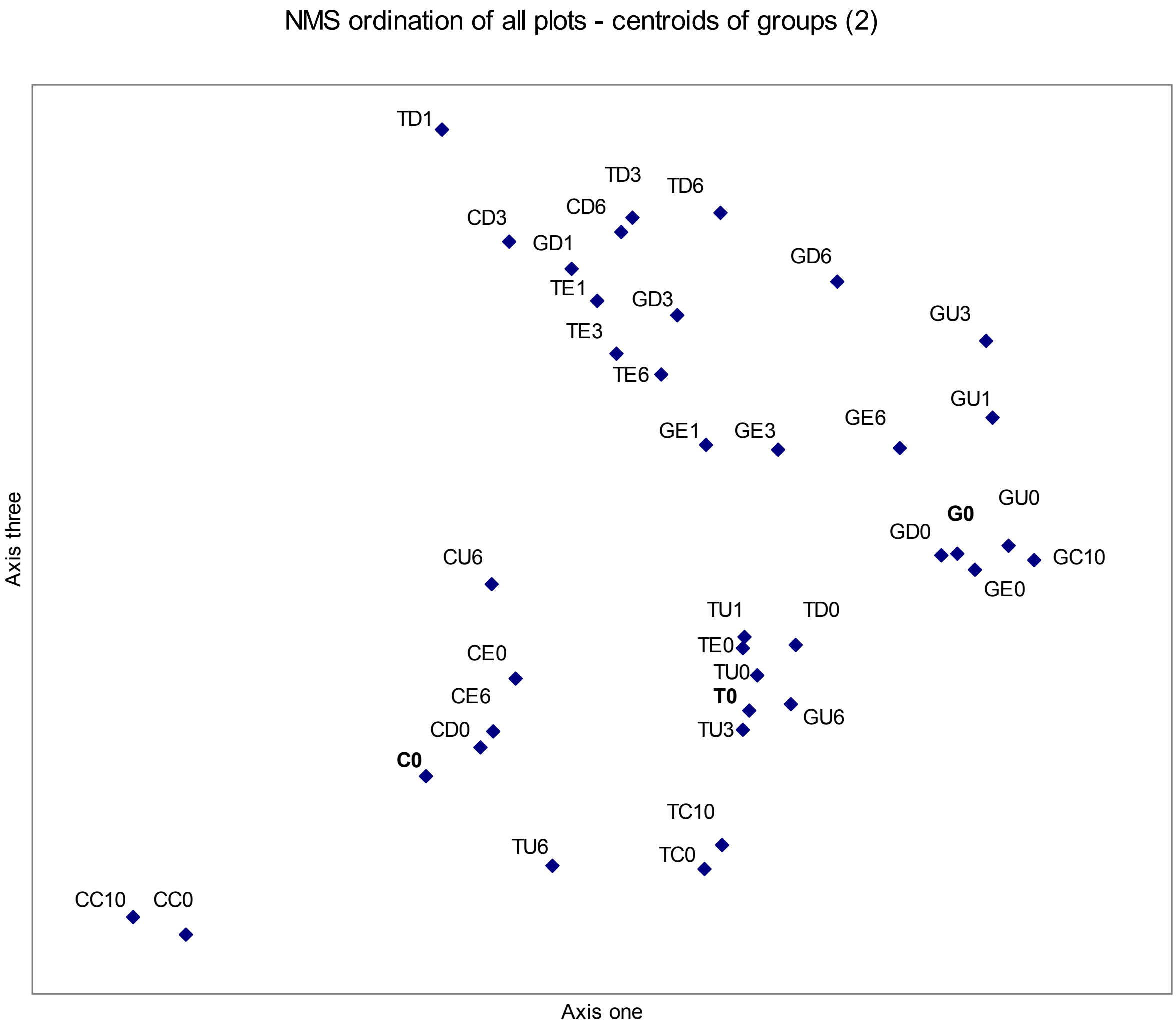


Figure 4.1b. NMS ordination, axis one versus axis three, of all the vegetation quadrats showing centroids of all the groups.

Labels as in Figure 4.1a.

Table 4.2. Species mean cover (Braun-Blanquet scale) and frequency of occurrence for all G-type disturbed quadrats. (Species with fewer than 5 occurrences throughout the sampling period have not been included in this table.)

Time (years)	Pre-harvest n = 87		1 n = 32		3 n = 84		6 n = 37			
	mean cover	frequency (%)	mean cover	frequency (%)	mean cover	frequency (%)	mean cover	frequency (%)	z test	sig at p < 0.05
Group one	constant									
gahngran	3.2	100	1.7	100	3.4	100	4.8	100	-	-
eucaobli	4.0	100	1.5	88	2.0	98	2.9	97	1.051	Not sig.
bauerubi	3.6	98	1.2	97	1.2	93	1.2	81	2.626	Sig.
nemasqua	3.0	93	0.8	78	0.9	89	0.9	84	1.480	Not sig.
leptlani	2.3	77	0.4	34	1.0	70	1.5	70	0.917	Not sig.
melasqur	2.1	69	0.8	53	1.0	60	0.8	43	3.181	Sig.
pomaapet	1.1	40	0.9	56	1.2	65	1.6	70	-3.999	Sig.
monoglau	0.3	18	0.2	16	0.4	38	0.3	32	-1.837	Not sig.
pimedrup	0.5	44	0.3	25	0.3	29	0.1	11	6.371	Sig.
histinci	0.2	16	0.2	19	0.4	39	0.2	11	0.949	Not sig.
acacmela	0.1	2	0.1	6	0.2	20	0.1	5	-0.857	Not sig.
caloelon	0.2	9	0.0	0	0.1	8	0.1	11	-0.407	Not sig.
coprquad	0.2	13	0.0	0	0.1	8	0.0	0	24.826	Sig.
pterescu	0.1	6	0.1	6	0.1	10	0.2	14	-1.416	Not sig.
hyporugo	0.0	0	0.1	6	0.2	23	0.0	3	-1.088	Not sig.
euchcoll	0.0	0	0.0	0	0.2	17	0.1	5	-2.601	Sig.
juncus	0.0	0	0.2	16	0.2	15	0.1	5	-2.395	Sig.
galiaust	0.1	13	0.0	0	0.1	7	0.0	0	24.826	Sig.
pomaelli	0.0	0	0.1	9	0.1	6	0.0	3	-1.088	Not sig.
cyatglau	0.1	8	0.0	0	0.0	4	0.1	5	0.802	Not sig.
acacmucr	0.0	1	0.0	0	0.1	4	0.1	5	-1.134	Not sig.
cotualpi	0.0	0	0.1	9	0.1	10	0.0	0	-1.837	Not sig.
acaenova	0.0	0	0.0	0	0.1	10	0.0	3	-1.837	Not sig.
cassacul	0.0	0	0.0	0	0.1	10	0.0	3	-1.837	Not sig.
epilobiu	0.0	0	0.0	3	0.1	10	0.0	0	-1.837	Not sig.
pterosty	0.0	5	0.0	0	0.0	5	0.0	3	0.667	Not sig.
acacia	0.1	6	0.0	0	0.0	4	0.0	0	11.355	Sig.
oleaargo	0.0	0	0.0	0	0.1	6	0.0	0	1.732	Not sig.
Group two	increased then decreased									
gonoteuc	0.1	15	1.5	97	1.6	95	0.2	24	-22.289	Sig.
violhede	0.0	1	0.7	72	0.7	64	0.1	14	-7.874	Sig.
isolepis	0.0	2	0.6	50	0.7	57	0.4	22	-6.649	Sig.
senemini	0.0	0	0.4	44	0.7	64	0.0	3	-8.001	Sig.
Group three	increased then steady									
acacvert	1.4	63	1.7	97	1.9	96	2.6	95	-9.045	Sig.
pultjuni	0.0	1	0.7	63	1.2	61	1.4	57	-6.772	Sig.
hibbempe	0.2	15	0.1	13	0.7	52	0.7	54	-4.651	Sig.
billlong	0.0	1	0.3	28	0.5	45	0.6	62	-7.535	Sig.
lepiensi	0.1	7	0.3	25	0.4	27	0.2	22	-2.067	Sig.
leptscop	0.0	2	0.1	9	0.1	10	0.4	24	-3.001	Sig.
oleastel	0.0	0	0.1	13	0.2	15	0.1	14	-2.290	Sig.
casspube	0.0	0	0.0	0	0.0	4	0.1	14	-2.290	Sig.
Group four	decreased but persistent									
blecwatt	1.0	76	0.3	25	0.5	43	0.3	24	7.524	Sig.
gleimicr	0.8	60	0.1	13	0.3	31	0.2	16	7.431	Sig.
Group five	decreased then sparse or absent									
phylaspl	0.4	28	0.0	0	0.0	1	0.0	3	9.090	Sig.
arispedu	0.4	38	0.0	0	0.0	2	0.0	3	12.599	Sig.
bankmarg	0.4	11	0.0	0	0.1	6	0.0	0	22.902	Sig.
tasmlanc	0.3	20	0.0	0	0.1	7	0.1	5	4.396	Sig.
dickanta	0.3	21	0.0	0	0.0	5	0.1	5	4.673	Sig.
clemaris	0.2	23	0.0	0	0.2	15	0.0	0	45.996	Sig.
cenaniti	0.1	13	0.0	0	0.0	2	0.0	0	26.751	Sig.
nothcunn	0.2	8	0.0	0	0.0	0	0.0	0	17.128	Sig.
athemosc	0.1	9	0.0	0	0.0	0	0.0	0	19.053	Sig.
corybas	0.1	15	0.0	0	0.0	0	0.0	0	30.600	Sig.
drymcyan	0.1	11	0.0	3	0.0	1	0.0	0	22.902	Sig.
eucrluci	0.1	5	0.0	0	0.0	1	0.0	0	11.355	Sig.
leptjuni	0.1	7	0.0	0	0.0	1	0.0	0	15.204	Sig.
grambill	0.4	40	0.0	0	0.0	0	0.0	0	78.712	Sig.
hymepelt	0.4	33	0.0	0	0.0	0	0.0	0	65.241	Sig.
hymeraru	0.2	20	0.0	0	0.0	0	0.0	0	40.222	Sig.
hymecupr	0.1	13	0.0	0	0.0	0	0.0	0	26.751	Sig.
hymeflab	0.1	9	0.0	0	0.0	0	0.0	0	19.053	Sig.
grammage	0.1	7	0.0	0	0.0	0	0.0	0	15.204	Sig.
micrpust	0.1	7	0.0	0	0.0	0	0.0	0	15.204	Sig.
ctenhete	0.1	6	0.0	0	0.0	0	0.0	0	13.279	Sig.
hymemarg	0.1	6	0.0	0	0.0	0	0.0	0	13.279	Sig.
tmesobli	0.1	6	0.0	0	0.0	0	0.0	0	13.279	Sig.

coupes. In all the other treatments seed was provided by retained trees and trees in the surrounding forest. The eucalypts clearly dominate the regenerating vegetation in most parts of the trial and are easily outgrowing the understorey (see Chapter 7 for details on the establishment and growth of the eucalyptus regeneration).

The most abundant understorey species in the disturbed G-type quadrats, and in fact throughout the trial is the sedge *Gahnia grandis*, commonly known as cutting grass. This species can regenerate from rootstocks in less disturbed vegetation but the majority of the regeneration was from ground-stored seed. By age three years the cover of this sedge was such that access through the harvested areas was difficult except on cut tracks. By age six years access was very difficult. Photo 4.1 shows access, such as it is, at age ten years.

Photo 4.1. Reassessing quadrats in WR1B at age ten years. The person in the photo (back to camera) is about 195 cm tall.

The most abundant and widespread taller understorey shrubs are *Acacia verticillata*, *Nematolepis squamea*, *Leptospermum lanigerum*, *Melaleuca squarrosa*, *Pomaderris apetala* and *Monotoca glauca*. The most abundant and widespread smaller understorey shrubs are *Bauera rubioides*, *Pultenaea juniperina*, *Hibbertia empetrifolia*, *Pimelea drupacea* and *Billardiera longiflora*.

Almost all of the regeneration arose from ground-stored seed or spores. The only species commonly observed to regenerate vegetatively was *Melaleuca squarrosa*, which coppiced from retained stumps. As noted below, some ferns also regenerated vegetatively. Vegetative regeneration was also observed occasionally in areas that were less physically disturbed by the harvesting and burning operations, but this was the exception, rather than the rule.

Four Group 2 species that were sparse or absent pre-harvest, *Gonocarpus teucrioides*, *Isolepis* spp, *Viola hederacea* and *Senecio minimus* flourished rapidly and abundantly in the post-disturbance phase but by age six years had declined again to very low levels. The *Isolepis* spp. flourished especially in very wet ground where their cover locally approached 100% by about age three years. By age six years however the *Isolepis* spp., none of which are very tall, were being outcompeted by the abundant and much taller *Gahnia grandis*. The abundance of *Viola hederacea* is notable. The species was recorded from just a single quadrat with a very low cover pre-harvesting, but regenerated rapidly and profusely post-disturbance. By age six years this species was also disappearing beneath the *Gahnia grandis*. The rapid, abundant and widespread response of all the species in this group suggests that all were represented in the ground-stored seed bank.

Three Group 3 species, *Pultenaea juniperina*, *Hibbertia empetrifolia* and *Billardiera longiflora* (and to a lower and more local level four other species) that were sparse or absent pre-harvest flourished in the post-disturbance phase and at age six years these species were well established. They are expected to decline over time given their sparsity in the pre-harvest vegetation which had been undisturbed since the 1934 fires. *Acacia verticillata* was common pre-harvest although many plants were senescent; post-harvest there was mass germination of this species across the trial, and despite heavy predation by browsing mammals young plants were abundant at age six years.

The cover of two Group 4 species, *Blechnum wattsii* and *Gleichenia microphylla*, declined post-disturbance compared to pre-harvest levels, but both persisted within the regenerating vegetation. Both species were observed regenerating from spores, but were also observed to regenerate vegetatively, both within the understorey islands (see also Chapter 5), and within the coupe proper.

There were a number of species (Group 5) present as scattered individuals prior to harvesting, that have not yet reappeared within the regenerating vegetation. This group includes a large number of rainforest species (*Phyllocladus aspleniifolius*, *Cenarrhenes nitida*, *Nothofagus cunninghamii*, *Atherosperma moschatum*), but also species that are typical of wet eucalypt forest (*Aristotelia peduncularis*, *Banksia marginata*, *Tasmannia lanceolata*, *Corybas* spp. and *Leptecophylla juniperina*). These latter species are presumed to be obligate seed-reproducing species as they appear not to be represented in the ground-stored seed bank.

A group of epiphytic ferns (Table 4.2, Group 5, five *Hymenophyllum* spp., two *Grammitis* spp., *Microsorum pustulatum*, *Ctenopteris heterophylla* and *Tmesipteris obliqua*) were very sparse in this vegetation type pre-harvest and were never recorded post-harvest.

G-type exposed

Most of the quadrats in this set are in the understorey islands in WR8H and WR8B, but the set also includes one quadrat in each of WR8C, WR8I, WR1E and WR1A.

The exposed G-type quadrats (Table 4.3) show a very similar response to the disturbed G-type quadrats. Dominant and persistent species in both sets are very similar. However there were some differences in the responses. In the exposed quadrats *Blechnum wattsii* and *Gleichenia microphylla* maintained their pre-harvest cover-abundance and frequency (Group 1) whereas they declined in the disturbed quadrats (Group 4, Table 4.2). *Pomaderris apetala* increased in cover and abundance more markedly (Group 3) in the exposed quadrats compared to the disturbed quadrats (Group 1, Table 4.2). Rainforest species and epiphytic ferns were too rare in this set for trends to be detected.

Table 4.3. Species mean cover (Braun-Blanquet scale) and frequency of occurrence for all G-type exposed quadrats. (Species with fewer than 5 occurrences throughout the sampling period have not been included in this table.)

Time (years)	Pre-harvest n = 12		1 n = 13		3 n = 13		6 n = 13			
	mean cover	frequency (%)	mean cover	frequency (%)	mean cover	frequency (%)	mean cover	frequency (%)	z test	sig at p < 0.05
Group one	constant									
gahngran	4.0	100	2.6	100	3.6	100	3.7	92	1.022	Not sig.
eucaobli	3.3	92	2.2	92	2.7	100	2.8	92	0.000	Not sig.
leptlani	2.9	100	1.7	92	2.3	100	3.4	100	-	-
bauerubi	3.4	100	1.7	100	1.5	92	1.8	85	1.455	Not sig.
nemasqua	3.1	100	1.3	77	1.6	100	1.5	85	1.455	Not sig.
melasqur	2.3	75	1.5	77	1.5	77	1.5	85	-0.970	Not sig.
acacvert	1.3	58	1.5	92	1.8	85	1.4	62	-0.285	Not sig.
blecwatt	1.2	83	0.8	77	0.8	69	0.7	62	1.499	Not sig.
gleimicr	0.9	67	0.2	15	0.8	69	0.7	62	0.357	Not sig.
monoglau	0.6	33	0.4	23	0.3	23	0.5	38	-0.357	Not sig.
caloelon	0.6	33	0.2	8	0.4	31	0.5	46	-0.904	Not sig.
pimedrup	0.3	33	0.5	46	0.5	46	0.3	31	0.150	Not sig.
corrlawr	0.3	17	0.2	23	0.3	31	0.4	31	-1.049	Not sig.
histinci	0.2	8	0.2	15	0.3	31	0.2	23	-1.235	Not sig.
bankmarg	0.4	17	0.0	0	0.2	15	0.2	15	0.194	Not sig.
leptscop	0.2	8	0.2	15	0.2	23	0.2	15	-0.679	Not sig.
cenaniti	0.1	8	0.1	8	0.2	23	0.2	15	-0.679	Not sig.
galiaust	0.1	8	0.2	15	0.2	23	0.1	8	0.000	Not sig.
isolepis	0.0	0	0.0	0	0.4	23	0.2	23	-1.893	Not sig.
oleastel	0.0	0	0.2	15	0.2	15	0.2	23	-1.893	Not sig.
dickanta	0.2	17	0.0	0	0.2	15	0.1	8	1.149	Not sig.
stictene	0.2	17	0.2	8	0.1	8	0.0	0	5.570	Sig.
lepiensi	0.1	8	0.1	8	0.2	15	0.1	8	0.000	Not sig.
acacmela	0.0	0	0.2	15	0.2	15	0.1	8	-1.022	Not sig.
Group two	increased then decreased									
gonoteuc	0.1	8	1.9	85	1.2	85	0.4	38	-7.470	Sig.
violhede	0.0	0	0.5	54	0.7	69	0.2	15	-5.168	Sig.
senemini	0.0	0	0.5	46	0.4	38	0.1	8	-2.712	Sig.
Group three	increased then steady									
pultjuni	0.1	8	0.6	46	0.6	46	1.2	62	-3.854	Sig.
pomaapet	0.2	8	0.4	38	0.5	38	0.6	38	-2.141	Sig.
hibbempe	0.1	8	0.2	15	0.7	62	0.6	46	-2.641	Sig.
billlong	0.1	8	0.5	54	0.4	38	0.5	46	-2.641	Sig.
Group five	decreased then sparse or absent									
arispedu	0.8	67	0.4	38	0.4	38	0.2	15	5.045	Sig.
tasmlanc	0.5	50	0.0	0	0.0	0	0.2	15	3.395	Sig.
phylaspl	0.5	33	0.1	8	0.0	0	0.1	8	3.192	Sig.

Table 4.4. Species mean cover (Braun-Blanquet scale) and frequency of occurrence for all G-type control quadrats. (Species with fewer than 5 occurrences throughout the sampling period have not been included in this table.)

Time (years)	Pre-harvest n = 24		10 n = 20			
	mean cover	frequency (%)	mean cover	frequency (%)	z test	sig at p < 0.05
Group one	constant					
bauerubi	3.8	92	4.4	100	1.319	Not sig.
eucaobli	3.5	96	2.8	85	1.378	Not sig.
leptlani	2.7	92	3.4	95	-0.616	Not sig.
gahngran	2.8	96	2.8	85	1.378	Not sig.
phebsqua	2.5	88	2.1	85	0.376	Not sig.
melasqur	1.2	46	1.1	40	0.548	Not sig.
acacrice	1.1	38	1.1	45	-0.629	Not sig.
acacvert	1.5	58	0.7	30	2.733	Sig.
pomaapet	0.9	46	1.0	65	-1.781	Not sig.
arispedu	0.8	75	0.9	85	-1.252	Not sig.
blecwatt	0.8	75	0.8	80	-0.559	Not sig.
corrlawr	0.5	38	0.8	45	-0.629	Not sig.
hakeliss	0.6	29	0.5	25	0.413	Not sig.
gleimicr	0.5	33	0.6	55	-1.978	Sig.
pimedrup	0.5	50	0.5	45	0.449	Not sig.
leptscop	0.6	21	0.3	15	0.751	Not sig.
lepiensi	0.4	25	0.4	25	0.000	Not sig.
eucrluci	0.3	21	0.3	20	0.112	Not sig.
proslasi	0.4	17	0.2	10	1.043	Not sig.
dickanta	0.3	33	0.2	20	1.453	Not sig.
monoglau	0.3	21	0.2	20	0.112	Not sig.
billlong	0.3	25	0.2	15	1.252	Not sig.
clemaris	0.3	25	0.2	15	1.252	Not sig.
galiaust	0.1	13	0.3	25	-1.239	Not sig.
gonoteuc	0.2	17	0.2	20	-0.335	Not sig.
bankmarg	0.3	13	0.1	5	1.642	Not sig.
phylaspl	0.3	13	0.1	5	1.642	Not sig.
stictene	0.1	13	0.2	15	-0.250	Not sig.
cyatjuni	0.2	17	0.1	10	1.043	Not sig.
grambill	0.2	21	0.1	5	3.283	Sig.
cyatglau	0.1	13	0.1	5	1.642	Not sig.
coprniti	0.1	13	0.1	10	0.447	Not sig.
tasmlanc	0.1	13	0.1	10	0.447	Not sig.
hymeraru	0.2	17	0.1	5	2.462	Sig.
histinci	0.2	17	0.1	5	2.462	Sig.

G-type control

This set of quadrats includes the internal and remote control plots plus one undisturbed quadrat in each of WR1E, WR8B, WR8C and WR1A. There were no significant changes over time in either species composition, cover or frequency (Table 4.4). The minor changes noted in the table may be due to the variation in sampling; four quadrats that were sampled pre-harvesting have not yet reached ten years post-disturbance so have yet to be resampled.

T-type disturbed

There was not a large number of quadrats in this set but they are well spread across five coupes. The set includes the harvested control quadrats for the understorey islands in WR8B and WR8H and quadrats in those two coupes plus WR8G, WR1A and WR5D.

The Group 1 species are all species that are more typical of wet eucalypt forest than rainforest, for example, *Bauera rubioides* and *Cyathodes glauca* (Table 4.5). *Senecio minimus* and *Gonocarpus teucrioides* (Group 2) flourished rapidly and abundantly in the post-disturbance phase but by age six years have declined again to very low levels. A suite of species more typical of wet eucalypt forest than rainforest have regenerated abundantly following the harvesting disturbance (Group 3). All regenerated from ground-stored seed or spores with the possible exception of *Histiopteris* (see below).

The only Group 4 species is *Blechnum wattsii*, which has regenerated vegetatively, as well as via spores. The rainforest species that dominated the understoreys in these quadrats pre-disturbance have all declined significantly in frequency post-disturbance (Group 5). Six years after the harvesting disturbance, only scattered seedlings of rainforest species were present in most of the quadrats. Very occasional coppice regeneration of *Nothofagus cunninghamii* and *Cenarrhenes nitida* was observed. The epiphytic ferns (Group 5, five *Hymenophyllum* spp, two *Grammitis* spp, *Ctenopteris heterophylla* and *Rumohra adiantiformis*) were common pre-disturbance but were never recorded post-disturbance.

Table 4.5. Species mean cover (Braun-Blanquet scale) and frequency of occurrence for all T-type disturbed quadrats. (Species with fewer than 4 occurrences throughout the sampling period have not been included in this table.)

Time (years)	Pre-harvest n = 20		1 n = 9		3 n = 17		6 n = 13			
	mean cover	frequency (%)	mean cover	frequency (%)	mean cover	frequency (%)	mean cover	frequency (%)	z test	sig at p < 0.05
Group one	constant									
bauerubi	0.5	30	0.2	22	0.4	35	0.4	38	-0.594	Not sig.
cyatglau	0.7	40	0.0	0	0.1	12	0.4	38	0.149	Not sig.
melasqur	0.3	10	0.0	0	0.2	12	0.2	23	-1.114	Not sig.
pimedrup	0.3	25	0.3	33	0.2	24	0.2	23	0.171	Not sig.
leptlani	0.6	20	0.0	0	0.2	18	0.2	15	0.505	Not sig.
tasmlanc	0.5	40	0.0	0	0.1	6	0.2	23	1.457	Not sig.
dickanta	0.2	15	0.0	0	0.1	12	0.2	23	-0.685	Not sig.
corrlawr	0.2	10	0.0	0	0.1	6	0.1	8	0.266	Not sig.
troccunn	0.2	20	0.0	0	0.0	0	0.1	8	1.595	Not sig.
hyporugo	0.0	0	0.1	11	0.2	18	0.2	8	-1.063	Sig.
Group two	increased then decreased									
senemini	0.0	0	0.4	44	0.5	53	0.3	31	-4.378	Sig.
gonoteuc	0.0	0	0.1	11	0.4	41	0.2	15	-3.437	Sig.
Group three	increased then steady									
eucaobli	3.0	85	1.6	89	2.8	94	3.2	100	-5.073	Sig.
nemasqua	1.5	55	0.7	67	0.8	82	0.9	85	-3.029	Sig.
pomaapet	1.5	55	2.2	89	2.8	82	3.3	85	-3.029	Sig.
acacvert	0.2	15	1.3	89	2.4	82	2.8	77	-5.312	Sig.
gahngran	0.9	50	0.9	89	2.4	94	2.6	92	-5.582	Sig.
monoglau	0.7	40	0.3	33	0.9	88	1.0	85	-4.544	Sig.
acacmela	0.7	25	1.0	89	0.5	53	0.6	54	-2.098	Sig.
histinci	0.1	5	0.1	11	0.8	41	0.7	23	-1.542	Sig.
acacdeal	0.0	0	0.0	0	0.4	24	0.8	38	-2.823	Sig.
billlong	0.0	0	0.6	56	0.3	29	0.5	54	-3.907	Sig.
hibbempe	0.0	0	0.0	0	0.4	29	0.5	38	-2.823	Sig.
Group four	decreased but persistent									
blecwatt	0.9	80	0.2	22	0.2	24	0.3	31	3.820	Sig.
Group five	decreased then sparse or absent									
anodbigl	3.2	75	0.2	22	0.2	18	0.2	15	6.059	Sig.
eucrluci	3.0	95	0.0	0	0.2	18	0.3	15	8.078	Sig.
phylaspl	1.9	75	0.0	0	0.1	12	0.2	15	6.059	Sig.
nothcunn	1.3	35	0.2	11	0.3	18	0.2	15	2.020	Sig.
athemosc	1.5	55	0.0	0	0.1	6	0.0	0	19.568	Sig.
cenaniti	1.3	70	0.0	0	0.1	6	0.2	15	5.554	Sig.
tasmlanc	0.5	50	0.0	0	0.1	0	0.2	15	3.534	Sig.
anopglan	0.7	30	0.0	0	0	0	0.0	0	10.509	Sig.
arispedu	0.5	45	0.0	0	0.1	6	0.0	0	15.944	Sig.
drymcyan	0.4	35	0.0	0	0.1	6	0.0	0	12.321	Sig.
townviri	0.4	40	0.0	0	0.0	0	0.0	0	14.132	Sig.
pittbico	0.4	15	0.0	0	0.0	0	0.0	0	5.073	Sig.
coprquad	0.3	20	0.0	0	0.0	0	0.0	0	6.885	Sig.
phylaspl	0.5	33	0.1	8	0.0	0	0.1	8	3.323	Sig.
grambill	1.0	100	0.0	0	0.0	0	0.0	0	35.875	Sig.
hymeraru	0.9	90	0.0	0	0.0	0	0.0	0	32.251	Sig.
hymeaust	0.5	50	0.0	0	0.0	0	0.0	0	17.756	Sig.
hymepelt	0.5	50	0.0	0	0.0	0	0.0	0	17.756	Sig.
grammage	0.5	45	0.0	0	0.0	0	0.0	0	15.944	Sig.
ctenhete	0.4	40	0.0	0	0.0	0	0.0	0	14.132	Sig.
hymecupr	0.3	30	0.0	0	0.0	0	0.0	0	10.509	Sig.
hymemarg	0.2	20	0.0	0	0.0	0	0.0	0	6.885	Sig.
rumoadia	0.2	20	0.0	0	0.0	0	0.0	0	6.885	Sig.

Table 4.6. Species mean cover (Braun-Blanquet scale) and frequency of occurrence for all T-type exposed quadrats. (Species with fewer than 4 occurrences throughout the sampling period have not been included in this table.)

Time (years)	Pre-harvest n = 19		1 n = 11		3 n = 11		6 n = 9			
	mean cover	frequency (%)	mean cover	frequency (%)	mean cover	frequency (%)	mean cover	frequency (%)	z test	sig at p < 0.05
Group one	constant									
phylaspl	1.8	84	0.5	45	0.6	55	0.6	56	1.871	Not sig. ?
tasmlanc	1.0	74	0.4	36	0.5	45	0.7	67	0.494	Not sig.
nemasqua	0.7	26	0.3	27	0.5	45	0.4	44	-1.203	Not sig.
anopglan	0.6	32	0.3	27	0.3	27	0.4	33	-0.071	Not sig.
leptlani	0.4	16	0.1	9	0.3	18	0.3	11	0.530	Not sig.
billlong	0.0	0	0.5	55	0.4	36	0.2	22	-1.761	Not sig.
acacdeal	0.0	0	0.0	0	0.2	9	0.3	22	-1.761	Not sig.
isolepis	0.0	0	0.0	0	0.3	27	0.2	22	-1.761	Not sig.
cyatglau	0.5	32	0.0	0	0.2	18	0.3	33	-0.071	Not sig.
prioceri	0.1	5	0.3	9	0.3	9	0.2	11	-0.636	Not sig.
troccunn	0.3	21	0.1	9	0.1	9	0.3	22	-0.080	Not sig.
dickanta	0.1	11	0.1	9	0.3	27	0.3	22	-0.881	Not sig.
bauerubi	0.1	5	0.2	9	0.2	18	0.2	22	-1.361	Not sig.
pittbico	0.2	11	0.0	0	0.2	18	0.1	11	0.000	Not sig.
clemaris	0.1	11	0.2	18	0.0	0	0.1	11	0.000	Not sig.
gleimicr	0.1	5	0.1	9	0.1	9	0.1	11	-0.636	Not sig.
senemini	0.0	0	0.2	18	0.2	18	0.0	0	-1.406	Not sig.
hymecupr	0.2	16	0.0	0	0.0	0	0.1	11	0.530	Not sig.
Group two	increased then decreased									
gonoteuc	0.0	0	0.3	27	0.5	55	0.0	0	-3.317	Sig.
Group three	increased then steady									
pomaapet	1.4	47	2.4	73	2.9	73	2.3	67	-17.333	Sig.
eucaobli	2.4	68	0.7	55	2.2	91	2.6	89	-2.226	Sig.
gahngran	1.2	68	1.1	91	1.5	91	2.7	100	-10.333	Sig.
acacvert	0.4	21	0.7	73	1.5	73	2.2	67	-3.245	Sig.
acacmela	0.4	16	0.6	55	0.9	73	1.2	78	-4.964	Sig.
monoglau	0.3	16	0.3	27	0.7	73	1.0	78	-4.964	Sig.
pimedrup	0.2	16	0.5	55	0.7	73	0.7	67	-3.597	Sig.
histinci	0.1	11	0.2	18	0.6	55	1.0	67	-3.950	Sig.
hibbempe	0.0	0	0.0	0	0.2	18	0.4	44	-2.940	Sig.
Group four	decreased but persistent									
eucrluci	3.4	100	1.5	64	1.5	55	1.9	56	2.940	Sig.
anodbigl	3.1	84	0.9	45	1.2	55	0.8	44	2.673	Sig.
athemosc	2.2	74	0.7	45	1.0	64	0.7	33	2.892	Sig.
nothcunn	1.5	47	1.2	27	0.9	36	0.6	22	2.002	Sig.
cenaniti	1.3	63	0.5	36	0.5	36	0.6	33	2.116	Sig.
blecwatt	1.2	95	0.8	55	0.6	45	0.7	44	3.408	Sig.
grambill	1.0	100	0.3	27	0.2	18	0.2	22	6.245	Sig.
Group five	decreased then sparse or absent									
coprquad	0.6	42	0.0	0	0.0	0	0.1	11	3.286	Sig.
arispedu	0.4	32	0.0	0	0.3	27	0.0	0	10.333	Sig.
townviri	0.4	42	0.0	0	0.0	0	0.0	0	13.667	Sig.
drymcyan	0.3	26	0.1	9	0.0	0	0.0	0	8.333	Sig.
corybas	0.3	26	0.0	0	0.0	0	0.0	0	8.333	Sig.
grammage	0.4	42	0.3	27	0.0	0	0.1	11	3.286	Sig.
hymeraru	0.7	68	0.0	0	0.0	0	0.1	11	6.042	Sig.
ctenhete	0.4	37	0.1	9	0.0	0	0.1	11	2.756	Sig.
hymepelt	0.5	47	0.0	0	0.0	0	0.0	0	15.333	Sig.
hymeaust	0.2	21	0.1	9	0.0	0	0.0	0	6.667	Sig.

T-type exposed

Quadrats in this set include those in the T-type understorey islands in the two CBS with understorey island coupes (WR8H and WR8B), that were left relatively undisturbed by the harvesting activity but were burnt during the regeneration burn, and a number of quadrats in WR8G and WR5D, that were located within unharvested forest but immediately adjacent to harvested areas.

The increased exposure to the sun and wind has clearly had an impact on these plots. The orchids (two species), filmy ferns and epiphytic ferns have declined most sharply, with only isolated occurrences being observed at age six years (Table 4.6, Group 5). *Gonocarpus teucrioides* (Group 2) flourished quickly then rapidly declined. A number of species typical of wet forests have increased in cover and abundance (Group 3) including *Pomaderris apetala*, *Gahnia grandis*, *Acacia verticillata*, *A. melanoxylon* and *Monotoca glauca*. The cover-abundance and frequency of occurrence of all the smaller rainforest tree species declined over time, but all were still present at age six years (Group 4).

The major difference between this set and the disturbed set above is that many of the rainforest species, both shrubs and ferns, persisted in the exposed quadrats, albeit often at levels that are lower than pre-disturbance (Group 4), whereas they had been lost from the disturbed quadrats.

T-type undisturbed

This set includes 12 quadrats in WR5D, five in WR8G and two in WR1A.

There were no significant changes over time in either species composition, cover or frequency (Table 4.7). There were minor variations in the cover and frequency of some species. This is the result of uneven sampling caused by the late harvesting of the group-selection coupe, WR8G (plots in WR8G were measured pre-harvest but to date have not reached age three years post-harvest).

T-type control

This set includes the internal and remote control plots. There were no significant changes over time in species composition, cover or frequency (Table 4.8).

Table 4.7. Species mean cover (Braun-Blanquet scale) and frequency of occurrence for all T-type undisturbed quadrats. (Species with fewer than 4 occurrences throughout the sampling period have not been included in this table.)

Time (years)	Pre-harvest n = 19		3 n = 12			
	mean cover	frequency (%)	mean cover	frequency (%)	z test	sig at $p < 0.05$
Group one						
eucrluci	3.3	89	3.7	100	-3.482	Sig.
eucaobli	3.5	89	2.4	75	1.120	Not sig.
nothcunn	2.0	68	2.0	67	0.074	Not sig.
anodbigl	2.2	79	1.8	75	0.320	Not sig.
phylaspl	1.8	84	2.0	92	-1.022	Not sig.
gahngran	1.8	84	1.4	75	0.720	Not sig.
nemasqua	1.6	53	1.1	33	1.473	Not sig.
athemosc	1.2	58	1.0	58	0.000	Not sig.
cenaniti	1.1	58	1.1	75	-1.360	Not sig.
blecwatt	0.8	63	1.0	67	-0.295	Not sig.
acacmela	0.9	37	0.9	42	-0.351	Not sig.
grambill	0.9	89	0.9	92	-0.383	Not sig.
anopglan	0.7	26	0.7	33	-0.516	Not sig.
hymeraru	0.6	58	0.7	67	-0.663	Not sig.
troccunn	0.6	53	0.6	50	0.208	Not sig.
tasmlanc	0.7	58	0.4	42	1.123	Not sig.
oritdive	0.6	21	0.4	25	-0.320	Not sig.
arispedu	0.5	47	0.5	50	-0.208	Not sig.
dickanta	0.5	16	0.3	8	1.022	Not sig.
bauerubi	0.7	21	0.0	0	6.963	Sig.
pomaapet	0.7	32	0.0	0	10.793	Sig.
pittbico	0.3	16	0.4	17	-0.092	Not sig.
grammage	0.4	37	0.3	33	0.295	Not sig.
hymepelt	0.4	37	0.3	25	0.960	Not sig.
cyatglau	0.3	26	0.3	25	0.080	Not sig.
monoglau	0.3	16	0.2	8	1.022	Not sig.
drymcyan	0.3	26	0.2	17	0.830	Not sig.
prioceri	0.2	16	0.2	17	-0.092	Not sig.
coprniti	0.2	21	0.0	0	6.963	Sig.
hymeaust	0.2	21	0.0	0	6.963	Sig.
rumoadia	0.2	21	0.0	0	6.963	Sig.

Table 4.8. Species mean cover (Braun-Blanquet scale) and frequency of occurrence for all T-type control quadrats. (Species with fewer than 4 occurrences throughout the sampling period have not been included in this table.)

Time (years)	Pre-harvest n = 20		10 n = 20			
	mean cover	frequency (%)	mean cover	frequency (%)	z test	sig at p < 0.05
Group one	constant					
eucrluci	3.5	95	4.3	100	-1.393	Not sig.
anodbigl	2.9	75	3.1	85	-0.970	Not sig.
blecwatt	2.9	100	2.8	100	-	-
athemosc	2.4	80	2.1	85	-0.485	Not sig.
nothcunn	2.0	75	1.8	65	0.726	Not sig.
eucaobli	1.5	40	1.4	45	-0.348	Not sig.
anopglan	1.6	75	1.2	65	0.726	Not sig.
grambill	1.0	100	1.0	100	-	-
prioceri	1.0	45	1.0	45	0.000	Not sig.
cenaniti	1.1	55	0.7	40	1.061	Not sig.
phylaspl	0.9	50	0.8	50	0.000	Not sig.
hymeraru	0.7	65	0.7	65	0.000	Not sig.
cyatglau	0.5	30	0.5	30	0.000	Not sig.
trocgunn	0.7	35	0.6	30	0.378	Not sig.
troccunn	0.8	50	0.8	50	0.000	Not sig.
hymeaust	0.5	45	0.3	60	-1.061	Not sig.
acacmela	0.4	10	0.4	15	-0.485	Not sig.
grammage	0.4	35	0.3	30	0.378	Not sig.
hymepelt	0.3	30	0.3	30	0.000	Not sig.
pittbico	0.4	20	0.3	15	0.485	Not sig.
arispedu	0.3	30	0.3	25	0.400	Not sig.
dickanta	0.3	15	0.2	10	0.577	Not sig.
townviri	0.4	35	0.2	15	1.940	Not sig.
drymcyan	0.2	15	0.2	20	-0.433	Not sig.
pimedrup	0.2	20	0.1	10	1.155	Not sig.
rumoadia	0.2	20	0.1	10	1.155	Not sig.
cyatjuni	0.1	10	0.2	15	-0.485	Not sig.
grampseu	0.1	10	0.2	15	-0.485	Not sig.
histinci	0.2	20	0.0	0	6.615	Sig.
stictene	0.1	10	0.1	10	0.000	Not sig.

C-type disturbed

The C-type disturbed quadrats are predominantly located in WR1A, plus one quadrat in WR8B.

The regenerating vegetation is dominated by species that are typical of wet eucalypt forest, not rainforest (Table 4.9). *Senecio minimus, Gonocarpus teucrioides, Isolepis* spp. *Hydrocotyle sibthorpioides* and *Acaena nova-zelandiae* (Group 2) flourished as rapidly as they subsequently declined. *Nothofagus cunninghamii* and *Eucryphia lucida* persisted at very low levels (Group 4). Scattered seedlings of both species were observed in the stripfell quadrats, as was coppice of *Nothofagus*. The tree fern *Dicksonia antarctica* and the ground fern *Blechnum wattsii* (Group 4) were observed to be recovering vegetatively. The other rainforest tree species (*Atherosperma moschatum*, *Phyllocladus aspleniifolius* and *Anodopetalum biglandulosum*) and the epiphytic ferns, were not (or very rarely in the case of *Rumohra adiantiformis*) observed post-disturbance (Group 5).

C-type exposed

The C-type exposed quadrats are a very small set of just six quadrats (Table 4.10). All are located in the retained belts in WR1A, either between the harvested strips or between the eastern strip and the patchfell. All were located on the western edge of the unharvested forest, where they were exposed to the afternoon sun. Whilst there was no direct damage to these quadrats from the harvesting, there was considerable subsequent windthrow, particularly of the taller understorey shrubs. This physical disturbance and resultant change in microclimate was sufficient to trigger germination of *Acacia verticillata*, *Monotoca glauca* and *Senecio minimus* (Group 3) whereas the epiphytic ferns (Group 5) declined.

C-type control

There were few significant changes over time on the control plot in either species composition, cover or frequency (Table 4.11). Two species have apparently disappeared from the control plot. *Polystichum proliferum* juveniles, with cover of less than 1%, were recorded on five of the quadrats in the control plot pre-harvest and none were observed at age ten years. *Clematis aristata* was also not found at age ten years (see notes re *Clematis aristata* below).

Table 4.9. Species mean cover (Braun-Blanquet scale) and frequency of occurrence for all C type disturbed quadrats. (Species with fewer than 5 occurrences throughout the sampling period have not been included in this table.)

Time (years)	Pre-harvest n = 39		3 n = 39		6 n = 10#			
	mean cover	frequency (%)	mean cover	frequency (%)	mean cover	frequency (%)	z test	sig at $p < 0.05$
Group one	constant							
eucaobli	4.0	92	2.0	90	2.7	100	-2.225	Sig.
acacmela	1.7	69	0.6	56	0.8	80	-0.870	Not sig.
histinci	0.8	56	1.6	74	1.5	70	-0.966	Not sig.
pimedrup	0.4	33	0.4	44	0.2	20	1.028	Not sig.
coprquad	0.6	36	0.0	0	0.2	20	1.265	Not sig.
melasqur	0.4	15	0.2	23	0.0	0	4.449	Sig.
cyatglau	0.2	13	0.0	3	0.1	10	0.316	Not sig.
hibbempe	0.1	3	0.1	13	0.1	10	-0.738	Not sig.
acacmucr	0.0	0	0.1	8	0.2	20	-1.581	Not sig.
pterescu	0.0	3	0.1	5	0.2	10	-0.738	Not sig.
clemaris	0.1	8	0.0	3	0.1	10	-0.211	Not sig.
bauerubi	0.0	0	0.1	10	0.1	10	-1.054	Not sig.
tasmlanc	0.1	8	0.1	8	0.0	0	2.225	Sig.
Group two	increased then decreased							
senemini	0.0	0	0.8	77	0.0	0	-11.427	Sig.
gonoteuc	0.0	0	0.6	59	0.0	0	-7.491	Sig.
hydrsibt	0.0	0	0.4	36	0.0	0	-4.684	Sig.
isolepis	0.0	0	0.3	31	0.0	0	-4.186	Sig.
acaenova	0.0	0	0.2	21	0.0	0	-3.220	Sig.
euchcoll	0.0	0	0.2	18	0.0	0	-2.926	Sig.
juncus	0.0	0	0.2	18	0.0	0	-2.926	Sig.
billlong	0.0	0	0.2	15	0.0	0	-2.623	Sig.
Group three	increased then steady							
gahngran	1.3	72	3.8	97	4.7	100	-8.581	Sig.
pomaapet	1.0	31	2.7	74	3.3	90	-6.219	Sig.
acacvert	0.0	3	2.0	85	1.9	80	-6.087	Sig.
nemasqua	1.0	28	0.6	64	0.9	60	-2.066	Sig.
monoglau	0.2	10	0.9	92	0.6	60	-3.227	Sig.
leptlani	0.2	8	0.6	54	0.6	40	-2.066	Sig.
acacdeal	0.0	0	0.3	26	0.8	40	-2.582	Sig.
hyporugo	0.0	3	0.5	54	0.4	40	-2.388	Sig.
Group four	decreased but persistent							
nothcunn	2.9	90	0.3	26	0.2	20	5.534	Sig.
eucrluci	1.6	54	0.1	8	0.2	20	2.688	Sig.
dickanta	2.4	85	0.7	44	0.5	40	2.905	Sig.
blecwatt	1.0	82	0.3	31	0.3	30	3.588	Sig.
Group five	decreased then sparse or absent							
athemosc	1.9	64	0.0	3	0.0	0	20.023	Sig.
phylaspl	1.3	64	0.1	5	0.0	0	20.023	Sig.
pittbico	0.5	31	0.0	0	0.0	0	9.535	Sig.
anodbigl	0.4	15	0.0	0	0.0	0	4.449	Sig.
grambill	1.0	97	0.0	3	0.0	0	30.511	Sig.
hymeraru	0.8	85	0.0	0	0.0	0	26.697	Sig.
hymecupr	0.7	67	0.0	0	0.0	0	20.976	Sig.
hymeflab	0.6	56	0.0	0	0.0	0	17.480	Sig.
rumoadia	0.4	44	0.0	0	0.1	10	3.584	Sig.
hymepelt	0.5	49	0.0	0	0.0	0	15.255	Sig.
ctenhete	0.4	41	0.0	0	0.0	0	12.713	Sig.
grammage	0.4	38	0.0	0	0.0	0	11.759	Sig.
tmesobli	0.3	33	0.0	3	0.0	0	10.170	Sig.
grampseu	0.2	21	0.0	0	0.0	0	6.356	Sig.
micrpust	0.2	15	0.0	0	0.0	0	4.449	Sig.

Note small sample size at age 6.

Table 4.10. Species mean cover (Braun-Blanquet scale) and frequency of occurrence for all C type exposed quadrats. (Species with fewer than 3 occurrences throughout the sampling period have not been included in this table.)

Time (years)	Pre-harvest n = 6#		6 n = 6#			
	mean cover	frequency (%)	mean cover	frequency (%)	z test	sig at p < 0.05
Group one	constant					
eucaobli	4.3	100	3.8	100	-	-
nothcunn	3.2	100	2.8	100	-	-
eucrluci	2.5	100	2.8	100	-	-
pomaapet	2.0	67	1.2	50	0.833	Not sig.
dickanta	1.8	83	1.3	50	1.617	Not sig.
athemosc	1.5	50	1.2	50	0.000	Not sig.
acacmela	1.2	33	1.3	83	-3.260	Sig.
phylaspl	1.3	67	1.0	67	0.000	Not sig.
grambill	1.0	100	1.0	100	-	Not sig.
nemasqua	1.0	33	0.8	50	-0.833	Not sig.
gahngran	1.0	50	0.7	50	0.000	Not sig.
hymeraru	1.0	100	0.7	67	1.719	Not sig.
blecwatt	1.0	83	0.5	50	1.617	Not sig.
histinci	0.8	67	0.7	67	-	-
pimedrup	0.8	67	0.7	67	-	-
coprquad	0.7	50	0.7	50	-	-
polyprol	0.3	33	0.3	33	-	-
rumoadia	0.3	33	0.3	33	-	-
anodbigl	0.2	17	0.3	17	-	-
hymeflab	0.3	33	0.2	17	1.043	Not sig.
Group three	increased then steady					
monoglau	0.3	17	1.0	100	-20.187	Sig.
acacvert	0.0	0	0.8	50	-2.449	Sig.
senemini	0.0	0	0.3	33	-1.719	Not sig.
Group five	decreased then sparse or absent					
hymecupr	1.0	100	0.5	50	2.449	Sig.
grammage	0.5	50	0.0	0	12.063	Sig.
hymepelt	0.5	50	0.0	0	12.063	Sig.
ctenhete	0.3	33	0.0	0	7.878	Sig.
grampseu	0.3	33	0.0	0	7.878	Sig.

Note small sample size.

Table 4.11. Species mean cover and frequency of occurrence for all C type control plots. (Species with fewer than 4 occurrences throughout the sampling period have not been included in this table.)

Time (years)	Pre-harvest n = 11		10 n = 10			
	mean cover	frequency (%)	mean cover	frequency (%)	z test	sig at p < 0.05
Group one	constant					
nothcunn	4.0	100	3.6	100	-	-
athemosc	3.2	91	3.6	90	0.105	Not sig.
dickanta	3.2	100	2.9	90	1.054	Not sig.
acacmela	1.9	73	1.5	50	1.455	Not sig.
grambill	1.0	100	0.9	90	1.054	Not sig.
hymeraru	1.0	100	0.9	90	1.054	Not sig.
histinci	0.8	64	1.0	50	0.885	Not sig.
hymeflab	1.0	100	0.8	80	1.581	Not sig.
eucaobli	0.5	18	0.8	30	-0.828	Not sig.
hymecupr	0.5	55	0.8	80	-1.976	Not sig.
blecwatt	0.9	91	0.4	40	3.292	Sig.?
hymeaust	0.5	45	0.5	50	-0.316	Not sig.
coprquad	0.5	36	0.5	50	-0.885	Not sig.
phympust	0.6	64	0.3	30	2.346	Sig.?
rumoadia	0.5	45	0.4	40	0.323	Not sig.
grampseu	0.5	45	0.3	30	1.035	Not sig.
tmesobli	0.5	45	0.3	30	1.035	Not sig.
pittbico	0.3	18	0.4	40	-1.420	Not sig.
grammage	0.4	36	0.3	30	0.414	Not sig.
hyporugo	0.2	18	0.1	10	0.843	Not sig.
Group five	decreased then sparse or absent					
polyprol	0.5	45	0.0	0	13.984	Sig.
pimedrup	0.4	36	0.1	10	2.741	Sig.
clemaris	0.3	27	0.0	0	8.263	Sig.

There are two plant species recorded in the summary tables that require comment as observing trends for these species is particularly difficult. *Clematis aristata*, commonly known as 'old man's beard', is a climber that is common but infrequent in wet forests. Young plants are often observed on the forest floor as a rosette of about four leaves. These plants persist for a short while but are then buried beneath the leaf litter layer and presumably die. The species was recorded occasionally in the pre-harvest sampling, but only very rarely thereafter. No trends can be confidently discerned in this species.

Histiopteris incisa, commonly known as 'batswing fern', is a ground fern. Its fronds die back in late autumn and winter each year and then regrow vigorously from the underground rhizomes each spring. The majority of the sampling in this study was done in winter and may therefore have under-recorded the true abundance of the species. This means that the trends observed here may not be truly reflective of its response to disturbance. The species also vigorously colonises disturbed ground via new plants, which were regularly observed throughout the trial, but it was often outcompeted by the *Gahnia*.

Species richness

On both the disturbed and exposed G-type quadrats, the average species richness increased to age three and then declined to age six years (Table 4.12). Conversely, on the disturbed T- and C-type quadrats the average species richness declined to age three years. It then stabilised in T-type quadrats but declined further in C-type quadrats to age six years. On the exposed T- and C-type quadrats there has been a small decrease in the average species richness from pre-harvest to age six years.

On the undisturbed quadrats on all three vegetation types there has been an apparent small decline in mean species richness from pre-harvest to age ten years.

Table 4.12. Mean species richness by understorey type, disturbance history and age across all floristic plots.

Age (years)		G			T			C		
		Dist	Exp	Undis	Dist	Exp	Undis	Dist	Exp	Undis
0	S	13.6	12.6	14.8	17.4	16.3	14.6	15.7	16.5	14.7
	n	87	12	24	20	19	39	39	6	11
1	S	12.2	13.8	-	8.1	11.4	-	-	-	-
	n	32	13	-	9	11	-	-	-	-
3	S	16.3	16.4	-	11.3	15.2	13.5	13.6	-	-
	n	84	10	-	17	11	12	39	-	-
6	S	11.5	13.4	-	11.3	15.2	-	10.1	15.8	-
	n	37	10	-	13	9	-	10	6	-
10	S	-	-	13.1	-	-	12.1	-	-	11.1
	n	-	-	20	-	-	20	-	-	10

Note: G = *Gahnia grandis* understorey type, T = thamnic rainforest understorey type, C = callidendrous rainforest understorey type

Dist = disturbed, Exp = exposed, Undis = undisturbed
S = species richness, n = number of quadrats represented within each set.

Discussion

No significant change in the flora of the control plots was detected over the sampling period; both the summary tables and the ordinations indicate that there has been no consistent change. This indicates that natural or temporal variation within the vegetation was not contributing to the observed treatment effects on the vegetation. The observed small decline in mean species richness in the control plots is attributed to observer error. The early ordinations revealed that there had been minor changes in the floristics of the control plots and examination of the data sheets revealed that this was due to the apparent loss of some species. The control plots were all re-checked and the missing species were located. Time, and the passage of time, as it is not possible to re-do the age three year surveys when six years have elapsed, prohibited such rechecking on all plots. Even on the control plots the missed species were few, and they are not considered significant in comparison to the overall sampling effort and trends identified in the data.

There was no discernable relationship between the harvesting and burning impacts as measured by the seedbed assessment and the floristic response at the quadrat level, nor could any relationship be discerned between the silvicultural system and the floristic response at the coupe level. This outcome is partly a function of the experimental design given that a fully replicated randomised block design may have been more able to reveal such relationships, if they exist. The absence of any clear relationships is also partly a function of the uniformity of the harvesting and burning impacts. Harvesting and burning in wet eucalypt forests have a consistent and significant impact on the vegetation. On most sites in this study, even at the lowest levels of overall impact, such as in the group selection treatment, the pre-harvest vegetation was completely flattened wherever harvesting took place. Whilst there was some variation in the local intensity of the regeneration burn, at the completion of the harvesting and burning treatments there was no intact vegetation on disturbed quadrats and the harvesting debris was usually burnt. At the completion of harvesting and burning, most of the disturbed quadrats looked the same.

The difficulty in finding a causal relationship between the effects of the harvesting and burning and the vegetation response is also partly a consequence of the uniformity of that response. The regenerating vegetation across the trial in these early years was very similar and dominated throughout by *Eucalyptus obliqua* seedling regeneration, a group of tall shrubs (*Nematolepis squamea*, *Acacia verticillata*, *A. dealbata*, *A. melanoxylon*, *Pomaderris apetala*, *Monotoca glauca*, *Leptospermum lanigerum* and *Melaleuca squarrosa*), occasional small shrubs (*Bauera rubioides*, *Pimelea drupacea*, and *Hibbertia empetrifolia*) and the abundant and ubiquitous sedge *Gahnia grandis*. Vegetative regeneration arose from rootstocks and rhizomes of a number of species including some later successional ones such as *Nothofagus cunninghamii*, but only rarely. The total species diversity of vascular plants across the trial is very low, and the same species dominate most quadrtas.

A third reason is the scale of these quadrats compared to the scale of the harvesting and burning impacts. The floristic quadrats were established as 10 m by 10 m plots as this was considered to be a size sufficiently small to be able to see the whole quadrat at once, which is important for estimating the cover-abundance scores, but large enough to adequately sample the inherent variation in the vegetation. It was clear from the post-harvesting and burning assessments of these quadrats that the disturbance impacts were never uniform across the quadrats, and that the seedbed on each quadrat was actually quite diverse. Microsite variation is known to influence germination and establishment of many species (Harper 1977; Battaglia 1993). From the early post-disturbance remeasurements of these coupes it appeared that there might have been a relationship between the nature of the harvesting and burning disturbances and the response of the vegetation, but this data set was not structured in a way that enables this relationship to be clearly defined.

To illustrate the nature of this diversity at the quadrat level, it was often apparent that where there had been no physical harvesting disturbance, but only a post-harvesting burning disturbance, there was strong germination of the sown eucalypts and of ground-stored seed, including abundant tall shrub species. In areas with significant physical harvesting disturbance resulting in gross disturbance and sometimes removal of the topsoil and compaction of the sub-soil layers, there was sparser eucalypt germination, little germination of the taller shrubs, and slow but ultimately overwhelming establishment of cutting grass. The way vegetation develops under these two contrasting conditions following harvesting and burning is likely to be quite different. In order to clearly determine whether these responses occur consistently across the disturbed areas, floristic quadrats would need to be established at the same scale as the soil disturbances, that is, square metres, not tens of square metres, or the treatment would need to be applied to a clearly defined area. Such an approach was used by Hindrum (2009) who established that by using 1 m by 1 m quadrats randomly located on areas of relatively uniform seedbed, that in fact it was apparent that the species diversity and composition was related to the nature of the harvesting and burning disturbances. Eucalypts and fireweeds are characteristic of well burnt seedbed, cutting grass is characteristic of unburnt and compacted seedbeds, and the greatness species diversity of understorey shrubs was found on undisturbed lightly to moderately well burnt quadrats.

Despite the relative uniformity of the post-harvesting vegetation it is evident that the pre-harvesting vegetation influenced the post-disturbance vegetation in two ways. Firstly, the pre-harvesting vegetation had a direct influence on the ground-stored seed bank. Only species that were present with sexually mature individuals on the site prior to the disturbance and whose seed can survive in the soil will be represented in the seed bank. Species that were never present on the site, or whose seed cannot survive for extended periods in the soil will be absent from the regenerating vegetation, except where their seed is wind or bird dispersed from local sources. Secondly, even with the intensity of the harvesting and burning disturbances applied in this trial there are always legacy plants that persist through the disturbances, and that are present in the recovering vegetation, if only at low levels. Rainforest species coppice was the most obvious instance of this but a number of smaller plants such as ground ferns were also observed regenerating vegetatively.

Quadrats which had carried sclerophyllous vegetation prior to the disturbances and which were left more exposed by the harvesting, that is those quadrats that lay within 10 m of the harvested areas, changed very little as a consequence of the disturbance, even when partly burnt. Exposed but otherwise undisturbed quadrats that carried rainforest species dominated understoreys prior to the disturbances were noticeably impacted by the exposure. Short-lived species established, and the more sun and wind sensitive species such as the filmy ferns (Neyland and Brown 1994; Westphalen 2003) declined or disappeared. Similar edge effects have been noted in variable retention harvesting in the Pacific Northwest, where there was a gradual decline in the abundance of herbs within the retained aggregates over the first few years post-harvesting (Nelson and Halpern 2005). As the surrounding regenerating vegetation establishes, this impact is expected to moderate (Denyer *et al.* 2006), but this remains to be tested at Warra.

On all the disturbed ground, regardless of the type of vegetation present pre-disturbance, there was a flush of short-lived species that were abundant by age three years and rare or absent by age six years. The widespread, abundant and rapid germination of these species, many of which were sparse or absent prior to the disturbance, points to a ground-stored seed origin. Many of the short-lived species that appear in temperate wet forests elsewhere in Australia following disturbance arise from ground-stored seed (Carroll and Ashton 1965; Floyd 1976; Tumino 1992; Attiwill 1994; Ashton and Martin 1996; Wang 1997; Burrows 2008) and presumably following their relatively short life they persist on the same site once again, as ground-stored seed. The widespread, abundant and rapid germination of the longer-lived sclerophyll shrubs, both those that were common on the site pre-harvesting (e.g. *Nematolepis squamea*) and those that were not (e.g. *Pultenaea juniperina*) also points to a ground-stored seed origin. That the sclerophyllous species germinated abundantly on sites that carried understoreys dominated by rainforest species pre-harvesting and burning demonstrates that the seed of these species is able to persist in the soil for decades at least. A long term study in the US has shown that the seed of a number of mostly annual or biennial species can persist in the soil for decades and in some cases centuries (Telewski and Zeevaart 2002), so it seems reasonable to assume that some species at Warra can adopt similar strategies.

Soil-stored seed is a common adaptation to disturbance in many ecosystems (Thompson 1986; Graham and Hopkins 1990; Fenner 2000). Numerous studies in Australia have shown that disturbance, particularly burning, in a range of natural ecosystems results in a rapid increase in plant species diversity which then either stabilises or declines over time (reviewed in Burrows (2008)), and many of these short-lived ephemerals arise from, and later persist as, ground-stored seed. For example, Harris

(2004) working in wet sclerophyll forests in the Otway Ranges in western Victoria observed a suite of herbaceous species that germinated, grew, set seed and died within about five years following harvesting. The majority of the longer-lived understorey species observed in Harris' study also germinated prolifically from ground-stored seed, with only a minor contribution from vegetative regeneration. By age 15 years, sclerophyllous shrubs (*Nematolepis*, *Pomaderris* and *Acacia* spp.), as at Warra, dominated the understorey vegetation.

The early response of the understorey to clearfelling and burning follows similar patterns in other cool temperate wet forests (e.g. Argentina, (Martinez Pastur *et al.* 2002) and Canada (Beese and Bryant 1999; Nguyen-Xuan *et al.* 2000; Haeussler and Bergeron 2004; Sullivan *et al.* 2008) and boreal wet forests (e.g. Sweden (Hannerz and Hånell 1997; Bergstedt and Milberg 2001) and Alaska (Rees and Juday 2002)). In the Pacific Northwest the early response to clearfelling and burning of the understorey was also a rapid flush of invading herbs and shrubs (e.g. Dyrness 1973; Schoonmaker and McKee 1988). In recent years planting of preferred species has replaced burning and natural regeneration in most Pacific Northwest harvesting operations (Tappeiner *et al.* 1997; Province of British Columbia 1999) and as a consequence the flush of herbs and shrubs is much less apparent (Halpern *et al.* 2005). This may be a consequence of the large amounts of harvesting debris that are left untreated on-site after harvesting (Halpern *et al.* 2005) but it also likely to be a consequence of the absence of burning (Scherer *et al.* 2000). Both heat (e.g. Floyd 1976) and smoke (e.g. Brown and van Staden 1997; Read *et al.* 2000) are known to promote germination of ground-stored seed of species adapted to fire disturbance. Burnt ground has also been shown to support more fire specialist species than disturbed ground (Rees and Juday 2002). Where harvesting is not followed by burning such species may be disadvantaged (McRae *et al.* 2001; Rees and Juday 2002).

This study was established to explore the hypothesis that the response of the vegetation to the harvesting and burning disturbance would vary according to the silvicultural system. However, based on results at both the quadrat and coupe level the original hypothesis cannot be accepted; there was no direct and immediate impact on the regenerating vegetation as a consequence of the silvicultural system that was applied in each coupe. The young regenerating vegetation was influenced more by the pre-harvesting vegetation than by the silvicultural system. Garandel *et al.* (2009) looked at the regenerating vegetation in a range of aggregated retention coupes throughout Tasmania and also found that the early regeneration was closely related to the pre-harvest vegetation.

However, at the coupe level and over the longer term, the different physical arrangements of the retained elements within the different treatments are likely to have an impact on the floristics. The response of the vegetation in created edges here supports the findings of Westphalen (2003) that edge effects in these forests extend for less than 10 m and that they have only a minor impact on the vegetation. The forest retained within the different treatments is therefore available to provide not only a lifeboating function (*sensu* Franklin *et al.* 1997), carrying those species and structures forward in time, but also as a source of propagules, to accelerate the colonisation of the harvested area by later successional species. For example, Tabor *et al.* (2007) have shown that rainforest tree species recruitment is influenced by proximity to harvested edges, with greater recruitment close to forest edges. In developing the range of alternatives to clearfelling that have been examined in this study, one consideration was maximisation of the area of the coupe that was under forest influence, that is, that remained post-harvesting within one tree height of retained forest. Such areas should be colonised more rapidly by later successional species, where they occur within the retained forest, than otherwise. Future studies will be able to examine this question, but it may take some decades for the forest influence to be reflected in the standing vegetation.

The results reported here demonstrate the importance both of the scale of sampling, of the need to target sampling in systems where there are very different impacts within the coupe and of the need to consider the long time frame of vegetation responses to disturbance. Only a few studies have truly considered the importance of the scale of sampling. Haeussler and Bergeron (2004) examined the response of the vegetation at microsite, site, stand and landscape scales and found that the results clearly changed with the scale of observation. In the present study , the plot size (10 m by 10 m) was probably too large to discern the relationships between the nature of the harvesting and burning disturbances and the vegetation responses, as each plot contained areas that had experienced a wide range of disturbance intensities. Hindrum (2009) examined the same relationships using plots of 1 m by 1 m, in which the disturbance intensity was more consistent, and found a significant relationship between the disturbance intensity and the vegetation response. Species diversity was highest on plots that were lightly to moderately well burnt and that had not been mechanically disturbed during the harvesting. Species diversity was lowest on unburnt, disturbed and compacted seedbed typical of primary snig tracks and firebreaks, which points to the need to keep these areas to a minimum. There are clearly differences in the responses when assessed at the plot (1 m by 1 m), plot (10m by 10 m), or coupe levels.

The EMEND trial in Alberta , Canada, examined the response of the vegetation to six levels of dispersed green tree retention harvesting, in which the 75% treatment was effectively an aggregated retention treatment in that only the extraction routes were harvested leaving undisturbed aggregates Craig and Macdonald (2009) found a stark contrast in the level of disturbance to harvested versus unharvested areas within the treatments, which demonstrates the need for carefully targeted sampling and separate analysis of the different components of the treatment, as was very much the case at Warra. Often, as discussed above, the harvested areas had all experienced similar impacts, and it was the contribution of the undisturbed retained areas within the coupes that was of most importance in distinguishing between silvicultural systems with respect to their longer term biological value.

All the studies cited here are reporting on vegetation responses over periods of less than 15 years as most of the silvicultural systems trials around the world were established from the early 1990s onwards. In all of the forests under study stand maturity will take many decades to reach, and in most, changes go on for centuries. Only with the benefit of long-term large scale studies, will we be able to truly understand the impacts of different silvicultural systems on our forests.

Appendix 4.1. Eight character species abbreviations and their corresponding full species name

Abbreviation	Species
acacdeal	*Acacia dealbata*
acacia	*Acacia* spp.
acacmela	*Acacia melanoxylon*
acacmucr	*Acacia mucronata*
acacrice	*Acacia riceana*
acacvert	*Acacia verticillata*
acaenova	*Acaena nova-zelandiae*
anodbigl	*Anodopetalum biglandulosum*
anopglan	*Anopterus glandulosus*
arispedu	*Aristotelia peduncularis*
athemosc	*Atherosperma moschatum*
bankmarg	*Banksia marginata*
bauerubi	*Bauera rubioides*
billlong	*Billardiera longiflora*
blecwatt	*Blechnum wattsii*
caloelon	*Calorophus elongatus*
cassacul	*Cassinia aculeata*
casspube	*Cassytha pubescens*
cenaniti	*Cenarrhenes nitida*
cirsvulg	*Cirsium vulgare*
clemaris	*Clematis aristata*
coprniti	*Coprosma nitida*
coprquad	*Coprosma quadrifida*
corrlawr	*Correa lawrenciana*
corybas	*Corybas* spp.
cotualpi	*Cotula alpina*
ctenhete	*Ctenopteris heterophylla*
cyatglau	*Cyathodes glauca*
dickanta	*Dicksonia antarctica*
drymcyan	*Drymophila cyanocarpa*
epilobiu	*Epilobium* spp.
eucadele	*Eucalyptus delegatensis*
eucaobli	*Eucalyptus obliqua*
euchcoll	*Euchiton collinus*
eucrluci	*Eucryphia lucida*
gahngran	*Gahnia grandis*
galiaust	*Galium australe*
gleimicr	*Gleichenia microphylla*
gonoteuc	*Gonocarpus teucrioides*
grambill	*Grammitis billardieri*
grammage	*Grammitis magellanica*
grampseu	*Grammitis pseudociliata*
hakeliss	*Hakea lissosperma*
hibbempe	*Hibbertia empetrifolia*
histinci	*Histiopteris incisa*
hydrsibt	*Hydrocotyle sibthorpioides*
hymeaust	*Hymenophyllum australe*
hymecupr	*Hymenophyllum cupressiforme*
hymeflab	*Hymenophyllum flabellatum*
hymemarg	*Hymenophyllum marginatum*
hymepelt	*Hymenophyllum peltatum*

Appendix 4.1 (cont) Eight character species abbreviations and their corresponding full species name

Abbreviation	Species
hymeraru	*Hymenophyllum rarum*
hyporugo	*Hypolepis rugosula*
isolepis	*Isolepis* spp.
juncus	*Juncus* spp.
lepidosp	*Lepidosperma* spp.
lepiensi	*Lepidosperma ensiforme*
leptjuni	*Leptecophylla juniperina*
leptlani	*Leptospermum lanigerum*
leptscop	*Leptospermum scoparium*
melasqur	*Melaleuca squarrosa*
micrpust	*Microsorum pustulatum*
monoglau	*Monotoca glauca*
nemasqua	*Nematolepis squamea*
nothcunn	*Nothofagus cunninghamii*
oleaargo	*Olearia argophylla*
oleastel	*Olearia stellulata*
oritdive	*Orites diversifolia*
phylaspl	*Phyllocladus aspleniifolius*
pimedrup	*Pimelea drupacea*
pittbico	*Pittosporum bicolor*
polyprol	*Polystichum proliferum*
pomaapet	*Pomaderris apetala*
pomaelli	*Pomaderris elliptica*
prioceri	*Prionotes cerinthoides*
proslasi	*Prostanthera lasianthos*
pterescu	*Pteridium esculentum*
pterosty	*Pterostylis* spp.
pultjuni	*Pultenaea juniperina*
rumoadia	*Rumohra adiantiformis*
senecio	*Senecio* spp.
senemini	*Senecio minimus*
strictene	*Sticherus tener*
tasmlanc	*Tasmannia lanceolata*
tmesobli	*Tmesipteris obliqua*
townviri	*Townsonia viridis*
troccunn	*Trochocarpa cunninghamii*
trocgunn	*Trochocarpa gunnii*
violhede	*Viola hederacea*

Chapter 5. Floristic and structural responses of the understorey islands, six years after harvesting.

Introduction

Clearfell, burn and sow (CBS) has been the standard silvicultural system used in lowland wet eucalypt forest in Tasmania since the 1960s (Hickey and Wilkinson 1999a). Excavators are commonly used for harvesting in these forests and for safety reasons, all the trees and most of the understorey are usually felled or pushed over. Pushing the understorey over during the course of harvesting is also perceived to assist in achieving a high intensity burn (Gilbert and Cunningham 1972), so residual areas of understorey that remain after harvesting are often 'scrub-rolled' to ensure an even distribution of fuel across the coupe (e.g. Jennings and Dawson 2000). Consequently, a typical clearfelled wet forest coupe has few if any standing trees or understorey shrubs by the time it is burnt.

Clearfelling followed by burning and sowing is perceived to have a number of advantages over selective harvesting methods (Hickey *et al.* 2001). Clearfelling creates the conditions necessary for successful regeneration of eucalypts (Gilbert 1959; Cunningham 1960a) and their subsequent rapid growth (King *et al.* 1993); it is relatively safe compared to selective felling (Mitchell 1993); burning the slash reduces the fuel load available to future wildfires (Forestry Tasmania 2005) and the lack of retained structure means that future forest operations, such as thinning, will be safer. Clearfelling has been compared to wildfires with respect to the creation of regeneration; '…a clearfelling and slash burning regime within the managed forests mimics the natural process of stand regeneration' (NAFI 1989; Attiwill 1994), although clearly there are structural differences between post-wildfire stands, that retain many elements of the pre-disturbance stand, and post-clearfelling stands, that retain few elements of the pre-disturbance stand (Lindenmayer *et al.* 1990).

Ough and Murphy (1996; Murphy and Ough 1997; Ough 2001) compared the understoreys in wildfire regeneration and CBS-based silvicultural regeneration in wet eucalypt forests in Victoria, and observed that the physical disturbances of clearfell harvesting resulted in significantly lower abundances of species that commonly regenerate vegetatively following wildfire, such as *Olearia* *argophylla* (musk), and *Dicksonia antarctica* and *Cyathea australis* (tree ferns). As musk and tree ferns are important hosts for epiphytic species, especially the smaller ferns and bryophytes, their loss can in turn result in reduced densities of these epiphytic species post-burning. Lower frequencies of epiphytic ferns in silvicultural compared to wildfire regeneration have been reported by a number of authors (e.g. Hickey 1994; Peacock and Duncan 1995; Chesterfield 1996; Harris 2004) and the loss of substrate is likely to be one of a number of reasons for the reduction in frequency. The harvesting disturbance, regeneration burn and increased insolation in the early years following the regeneration burn also contribute (Hickey 1994; Neyland and Brown 1994; Westphalen 2003).

The concept of 'understorey islands' was developed in Australia by Ough and Murphy (1998) for regrowth *E. regnans* (mountain ash) forests in Victoria. They proposed that machinery exclusion zones, or understorey islands, should be defined prior to the commencement of harvesting. During the course of the harvesting, the understorey within these islands would be retained intact in order to maintain a greater floristic and structural diversity within the harvested area. Where possible, the islands would be located so as to capture identified target species. The understorey islands would be burnt during the regeneration burn (Ough and Murphy 1998, Hickey *et al.* 2001), but because they contained undisturbed and hence green vegetation, they would burn at a lower intensity than the rest of the coupe and would retain an unburnt core post-fire. The absence of physical disturbance to the understorey from the harvesting activity should lead to greater vegetative recovery following the regeneration burn.

The species identified by Ough and Murphy (1998) as being particularly disfavoured by CBS regimes, *O. argophylla* and the two species of tree fern referred to above, were not a feature of the pre-harvest vegetation at Warra. There were a number of species present that were known to be able to regenerate vegetatively, so long as their root systems were left relatively undisturbed through the course of the harvesting, including both shrubs e.g. *Melaleuca squarrosa* and a number of species of ground fern including *Blechnum wattsii* and *Gleichenia microphylla*.

Two ‘clearfell burn and sow with understorey islands’ coupes were established within the Warra trial. This chapter reports on the islands six years after establishment. The study tested the following hypotheses;

- Retention of understorey islands in tall wet *Eucalyptus obliqua* forest increases the post-harvest recovery of the understorey vegetation.
- Retention of understorey islands increases the post-harvest structural diversity within the harvested coupe.

Methods

Coupe establishment

Two ‘clearfell, burn and sow (CBS) with understorey islands’ coupes, WR8B and WR8H, were established in the Warra silvicultural systems trial in 2001 and 2002, respectively. Each coupe contained two distinct understorey types, G type and T type (Chapter 3). T type is thamnic rainforest (*sensu* Jarman *et al.* 1984) comprising a mixture of rainforest species (*Anodopetalum biglandulosum*, *Phyllocladus aspleniifolius*, *Eucryphia lucida*, *Atherosperma moschatum* and *Nothofagus cunninghamii*, plus a diverse group of epiphytic ferns and smaller shrubs). G type is wet sclerophyll, with a tall shrub layer dominated by *Leptospermum lanigerum* and *Melaleuca squarrosa*, over a dense ground layer of *Bauera rubioides* and *Gahnia grandis*. The two understorey types were separated spatially, with the rainforest understorey occurring on a steeper bank which extended across the northern side of both coupes, whilst the sclerophyllous understorey extended over the gentler, more poorly drained slopes on the southern side.

Understorey island establishment

Two understorey islands, each of 40 m by 20 m, were marked for retention within each understorey type within each coupe, creating eight islands in total (Figure 5.1). The islands were at least 60 m from the coupe boundary and from each other. All were clearly marked on the ground with flagging tape and on the coupe plan so that the contractor could identify the islands during harvesting. During harvesting, merchantable overstorey trees were able to be felled out of the understorey islands where this could be done without significant disturbance to the retained understorey. Trees which leant over the islands, such that their harvesting may have resulted in damage to the understorey, were retained whether they were in or adjacent to the islands.

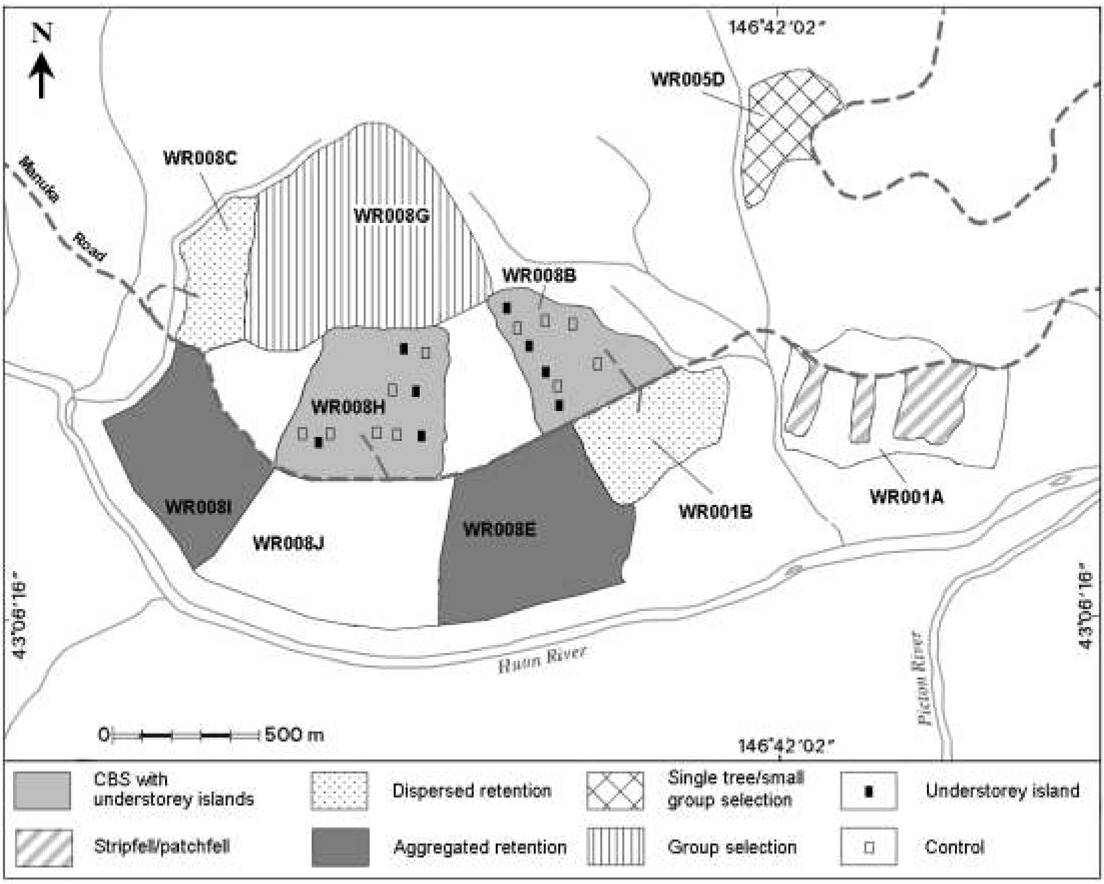


Figure 5.1. Layout of the understorey islands and controls in WR8H and WR8B.

Floristic and structural assessments

In the centre of all the islands, two adjacent 10 m by 10 m floristic quadrats were established and the projective foliage cover of each higher plant species present using a modified Braun – Blanquet scale (Mueller-Dombois and Ellenberg 1974) (1 = 0 to 1%, 2 = 2 to 5%, 3 = 6 to 25%, 4 = 26 to 50%, 5 = 51 to 75% and 6 = 76 to 100%) was recorded prior to harvesting. The dominant species within each of a range of height classes and the cover-abundance of the vegetation within each height class was also recorded. Only live vegetation was recorded. At least two adjacent pairs of floristic quadrats were also established within each understorey type within each coupe to serve as controls for the understorey islands (Figure 5.1). The controls were marked to enable their relocation but in a way that was not obvious to the harvesting contractor. The controls were assessed as for the understorey islands but were then clearfelled along with the rest of the coupe.

The floristics and structure of each quadrat within each island and control plot were assessed prior to the commencement of harvesting and again one, three and six years after the burn, following the same methodology as used prior to harvesting. Each island and control was identified with a unique code, derived from the coupe code (8B or 8H), a sequential number and the two floristic quadrats were numbered 1 (north) and 2 (south) (hence for example 8B 5 1 and 8B 5 2 are the two floristic quadrats within the one island, 8B 5).

Following completion of harvesting, an excavator was used to rake harvesting debris away from each island, creating a mineral earth swathe about 4 m wide around each island, so that the high intensity regeneration burn planned for each coupe would have the least possible impact on the islands. All the islands and controls were visited briefly prior to the burn and notes recorded about their condition. Both coupes were burnt by a high intensity burn in the autumn following the completion of harvesting.

Shortly after the burn, the nature of the seedbed was assessed systematically across the coupe, and in the floristic quadrats within each understorey island and control. For the coupe seedbed assessment, a randomly located 100 m by 10 m grid was placed over the coupe. The nature of the seedbed was assessed at each intersection point of the grid. The intensity of the burn and impact of the harvesting disturbance on the soil at each point was classified as shown in Table 5.1. Note that where the soil had been heated sufficiently to rate as burnt-to-mineral (BM) or oxidised (B2) soil, a disturbance class was not assigned to the point as it was considered impossible to distinguish pre-burn disturbance effects. The combination of burnt-to-litter (BL) and compacted (D2) seedbed did not occur in either coupe. For the understorey islands and controls, the seedbed was assessed in each 10 m by 10 m floristic quadrat. For each quadrat, an estimate was made of the proportion that fell into each seedbed class using the modified Braun-Blanquet scale: 1 = <1%, 2 = 1 – 5%, 3 = 6 – 25%, 4 = 26 – 50%, 5 = 51 – 75%, 6 = 76 –100% (Mueller-Dombois and Ellenberg, 1974). General notes about the condition of each understorey island were also recorded.

Table 5.1. Seedbed burn and disturbance classes.

<u>Burn classes</u>
B0, unburnt. BL, burnt but unburnt litter still present. BM, burnt to mineral soil. B2, ashbed.

<u>Disturbance classes</u>
D0, undisturbed. D1, revealed. D2, compacted

<u>Seedbed classes</u>

	D0	D1	D2
B0	1	2	3
BL	4	5	n/a
BM		6	
B2		7	

Analysis

All the statistical analyses were completed using Statgraphics Plus 2.1 (Statistical Graphics Corporation 1994-1996). Non-metric multi-dimensional scaling (NMS) was used to examine the floristic and structural data. All the ordinations were done using the slow and thorough option within PC-ORD (McCune and Mefford 1999), in which the maximum number of iterations is 400, the instability criterion is set at 0.00001, up to 6 axes may be used and there are 40 runs completed with real data and 50 with randomised data. In most cases repeated ordinations were run to ensure that consistent results were being obtained. Two-way indicator species analysis (TWINSPAN) was used to identify those species which influenced the final floristic ordination; these analyses were also completed using PC-ORD (McCune and Mefford, 1999). The floristic data was analysed across time to compare changes between the vegetation pre-harvesting, immediately post-harvesting and at ages one, three and six years post-harvesting. The structural data was analysed six years post-harvesting.

T-tests were used to compare the change in Euclidean distance within the final ordination space from pre-harvesting to age 3 years and to age 6 years, for the island quadrats compared to the control quadrats, and for both understorey types. The Euclidean distances were squared in order to normalise their distribution. The standard skewness and standard kurtosis were checked, and found to be acceptable. The standard deviations of each data set were checked to ensure that they were not statistically significantly different.

Summary tables were prepared based on the floristic data. These show the mean cover-abundance and percentage frequency of each species within each set of quadrats within both the islands and the controls, for time pre-harvest and age six years. The age one and age three year's data are not presented in the tables. At age one there had been insufficient time for much vegetative recovery and the data is not informative. At age three there was an abundance of early colonising species (Chapter 4), but this was not considered to be informative of the longer term trends which are of most interest here. Within the summary tables the species were grouped. Group one comprises those species whose cover and/or frequency remained relatively constant over the sampling period, or where the species was recorded too rarely to confidently ascribe a trend. Group two comprises those species whose cover and/or frequency decreased in the control quadrats but not in the understorey island quadrats. Group three comprises those species whose cover and/or frequency decreased in both the control quadrats and the understorey island quadrats. Group four comprises those species whose cover and/or frequency increased in both the control quadrats and the understorey island quadrats. Species recorded on less than three occasions were not included in the tables.

Multiple regression was used to examine the relationship between floristic change and the impact of the regeneration burn; the change in Euclidean distance within the final ordination space between each quadrat pre-harvesting and at age three and age six years was calculated and regressed against the cover-abundance value for each seedbed type for each quadrat as assessed immediately after the burn. Forward stepwise selection was used to include only significant variables in the model. The model performance was assessed using the r^2 statistic. Correlations deriving from the order of the data were checked using the Durbin-Watson statistic and residual plots were checked for outliers.

Results

Post-harvesting, pre-burning

At the completion of harvesting, but before burning, all the understorey islands were clearly evident within the coupe (Photo 5.1). Occasional overstorey trees had been felled out of the edges of a few of the islands, but none of the felling had occurred within any of the floristic quadrats. The sclerophyll (G type) islands were effectively undisturbed in both coupes. Windthrow had affected all the rainforest (T type) understorey islands, particularly those in WR8H (Photos 5.2a and 5.2b). The islands in WR8H, located in the eastern part of the coupe, were more exposed to the prevailing westerly winds than those in WR8B.

There was no significant mechanical disturbance to the seedbed in any of the islands. Most of the disturbed seedbed recorded was a consequence of windthrow of the retained understorey shrubs and small trees. The only significant area (> 25% of the quadrat) of exposed mineral soil was in quadrat 8B 7 1; this was the result of windthrow. By chance, given that the harvesting contractor did not know where the controls were located, mechanical disturbance affected only small areas (<5%) of any of the controls except for 8B 6 1 and 8H 234 1. Both had been traversed by a rubber-tyred skidder during the course of harvesting, causing compaction to a corner of each quadrat and some disturbance of the topsoil.

Photo 5.1. Understorey island 8H 40S at the completion of harvesting and before burning.

Photo 5.2a. Understorey island 16 shortly after it was isolated during the course of the harvesting.

Photo 5.2b. The same island, three months later.

Post-burning seedbed – coupe

The regeneration burns were hot enough to create burnt seedbed over the majority of both coupes (Tables 5.2 and 5.3). Unburnt seedbed occupied less than 20% of the coupe areas and was largely restricted to the fireline (the swathe around the perimeter of the coupes that was cleared by machine prior to lighting), and to shaded areas on the western side of each coupe. Oxidised (B2) soil was predominantly found in and under the windrow of harvesting debris created by clearing the fireline. The most common seedbed classes were burnt-to-litter (BL) and burnt-to-mineral soil (BM), which generally occurred together as a complex mosaic, reflecting the uneven accumulation of harvesting debris prior to the burn.

Table 5.2. Seedbed plots by burn and disturbance class, WR8H (n, %).

	D0	D1	D2	Total	% (Burn class)
B0	2 (1)	22 (9)	9 (4)	33	13
BL	60 (24)	59 (24)	n/a	119	47
BM		76 (30)		76	30
B2		27 (10)		27	10

n = 255

Table 5.3. Seedbed plots by burn and disturbance class, WR8B (n, %).

	D0	D1	D2	Total	% (Burn class)
B0	7 (4)	20 (13)	3 (2)	30	19
BL	29 (18)	13 (8)	n/a	42	27
BM		47 (30)		47	30
B2		38 (24)		38	24

n = 157

Post-burning seedbed – understorey islands and controls

Most of the understorey islands were at least partly burnt during the regeneration burn (Table 5.4). The only island which remained entirely unburnt after the burn was 8B 193. Apart from some desiccation of the vegetation at the edges of this island, resulting from the increased exposure to wind and sunlight that followed harvesting of the rest of the coupe, the island remained in a similar condition six years after harvesting to that prior to harvesting. In island 8B 5, the burn was of relatively low intensity; unburnt seedbed covered more than 75% of one quadrat and more than 25% of the other. Island 8H 16 had a small area of unburnt seedbed. All the other islands were almost completely burnt (> 95%) and the distribution of seedbed classes was in similar proportions to that throughout the remainder of the two coupes. The windthrow of the understorey in the WR8H islands presumably accelerated drying and resulted in hotter burns than anticipated within these islands. The controls (Table 5.4) all burnt vigorously. Less than 5% of any control quadrat remained unburnt; most of the seedbed was rated as burnt-to-litter (BL) or burnt-to-mineral soil (BM) and there were occasional small patches of oxidised soil (B2) in most quadrats.

Table 5.4. Seedbed assessment (cover-abundance score for each seedbed type) of the floristic quadrats within the understorey islands and controls (Each island and control was identified with a unique code, derived from the coupe code (8B or 8H), a sequential number and the two floristic quadrats were numbered 1 (north) and 2 (south) (hence for example 8B 5 1 and 8B 5 2 are the two floristic quadrats within the one island, 8B 5)).

	Island Type		Burn code				Disturbance code		
Plot number	Under-storey type[1]	Island or Control	BO	BL	BM	B2	DO	D1	D2
8H 13 1	T	Island	0	5	4	3	6	2	0
8H 13 2	T	Island	0	4	5	3	6	2	0
8H 16 1	T	Island	1	5	3	3	6	1	0
8H 16 2	T	Island	3	4	3	3	6	2	0
8B 7 1	T	Island	0	3	4	2	5	4	0
8B 7 2	T	Island	2	5	3	1	6	2	0
8B 5 1	T	Island	4	3	3	3	6	1	0
8B 5 2	T	Island	6	2	2	1	6	0	0
8H 106 1	G	Island	0	5	3	2	6	1	0
8H 106 2	G	Island	0	6	2	0	6	2	0
8H 40S 1	G	Island	0	3	6	1	6	1	0
8H 40S 2	G	Island	0	3	6	1	6	1	0
8B 193 1	G	Island	6	0	0	0	6	0	0
8B 193 2	G	Island	6	0	0	0	6	0	0
8B 68 1	G	Island	2	4	4	2	6	0	0
8B 68 2	G	Island	2	5	4	0	6	0	0
8H 9 1	T	Control	0	2	5	3	6	2	0
8H 9 2	T	Control	0	2	3	5	6	2	0
8H 12 1	T	Control	0	5	4	3	6	1	0
8H 12 2	T	Control	0	3	2	6	6	2	0
8B 4 1	T	Control	0	2	6	2	6	0	0
8B 4 2	T	Control	0	3	6	2	6	0	0
8B 6 1	T	Control	0	2	5	4	6	0	0
8B 6 2	T	Control	1	0	6	3	5	4	2
8H 234 1	G	Control	2	6	3	1	4	5	3
8H 234 2	G	Control	0	4	5	3	6	1	0
8H 264 1	G	Control	2	4	5	2	6	2	1
8H 264 2	G	Control	0	6	2	2	6	1	0
8H 418 1	G	Control	0	5	4	2	6	2	0
8H 418 2	G	Control	0	5	4	2	6	1	0
8H 518 1	G	Control	2	4	5	2	6	2	0
8H 518 2	G	Control	2	6	2	2	6	2	0
8B 124 1	G	Control	0	2	5	4	6	0	0
8B 124 2	G	Control	0	4	3	3	6	0	0
8B 232 1	G	Control	0	3	5	2	6	2	0
8B 232 2	G	Control	0	2	6	2	6	2	0
8B 130 1	G	Control	2	2	4	4	6	2	2
8B 130 2	G	Control	2	3	5	2	6	2	3

Note 1. Understorey type; T = Thamnic type, G = Gahnia type.
Note 2. Cover abundance scores: 1 = <1%, 2 = 1 – 5%, 3 = 6 – 25%, 4 = 26 – 50%, 5 = 51 – 75%, 6 = 76 –100%.

Floristic ordinations

There was a significant reduction in stress from the one dimensional (32) to the two-dimensional (21) and again to the three-dimensional result (15) but not to the fourth (13), which suggests that the data are three-dimensional (Figure 5.2). The final ordination of all the quadrats is shown in Figure 5.3.

In order to more clearly elucidate the patterns revealed by the ordination, a series of figures is presented. All were derived from the final ordination (Figure 5.3), but the groups are presented differently and in many cases only a subset of quadrats is shown. In Figure 5.4, the pre-harvest quadrats are all shown in solid black, and all the post-harvest quadrats (i.e. from age one, three and six years post-harvest) are shown in outline. This figure shows that pre-harvesting, the quadrats were separated into two discrete groups, those with sclerophyll (G type) understoreys and those with thamnic rainforest (T type) understoreys, as recognised prior to the establishment of this experiment. Post-harvesting, the T and G type quadrats remain almost as discrete groups but have shifted in the ordination space and are more similar to each other post-harvesting than they were pre-harvesting. As the two floristic types are separate in the ordination space, for clarity subsequent ordination figures present data for one understorey type or the other.

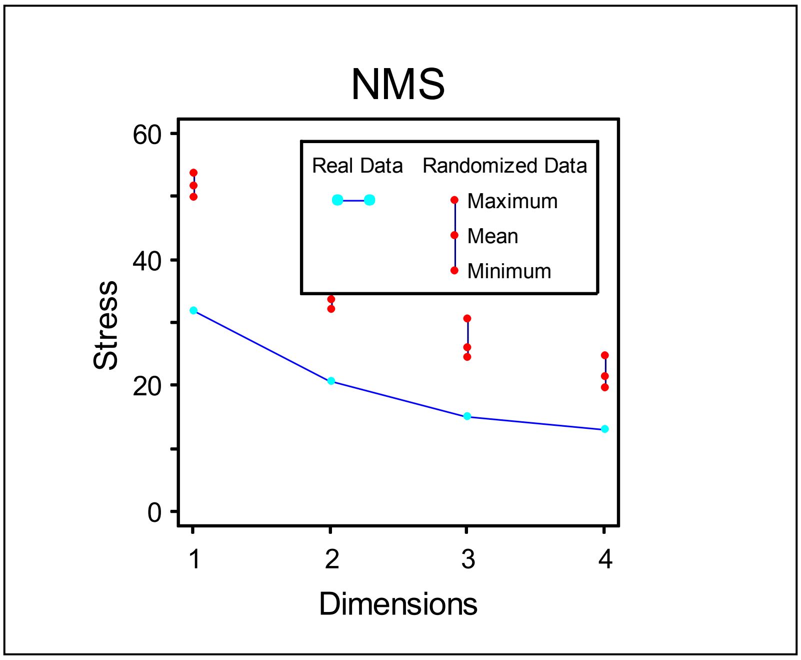


Figure 5.2. Stress plot for the final ordination of the floristic data from the understorey islands and controls.

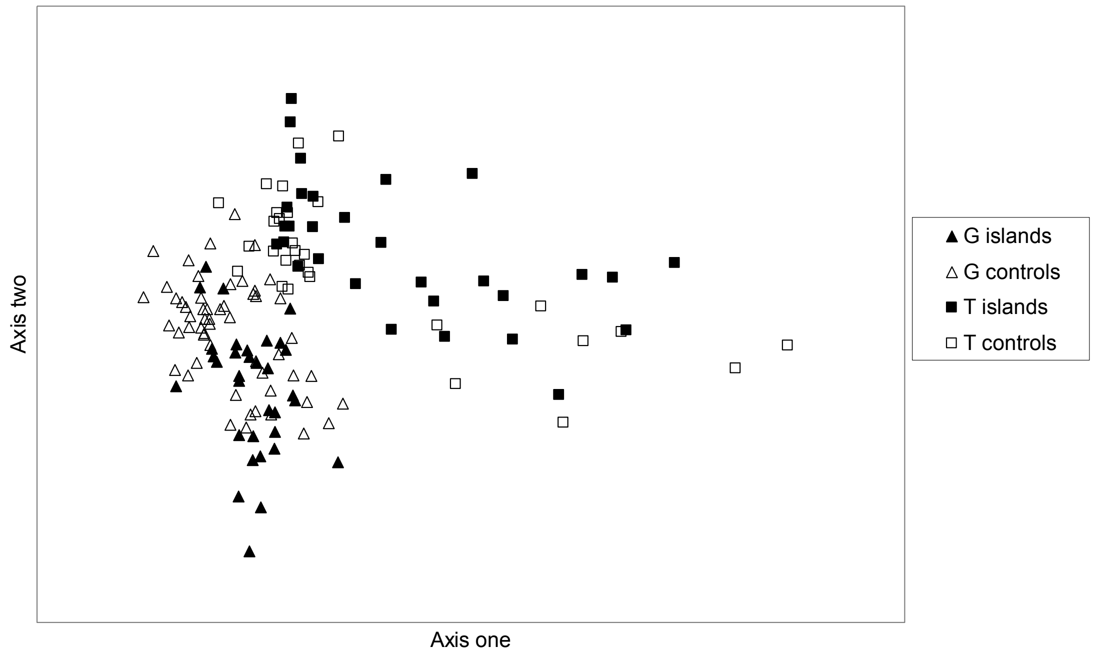


Figure 5.3a. Ordination plot (NMS, showing axis one versus axis two) for all the understorey island and control plots at all ages.

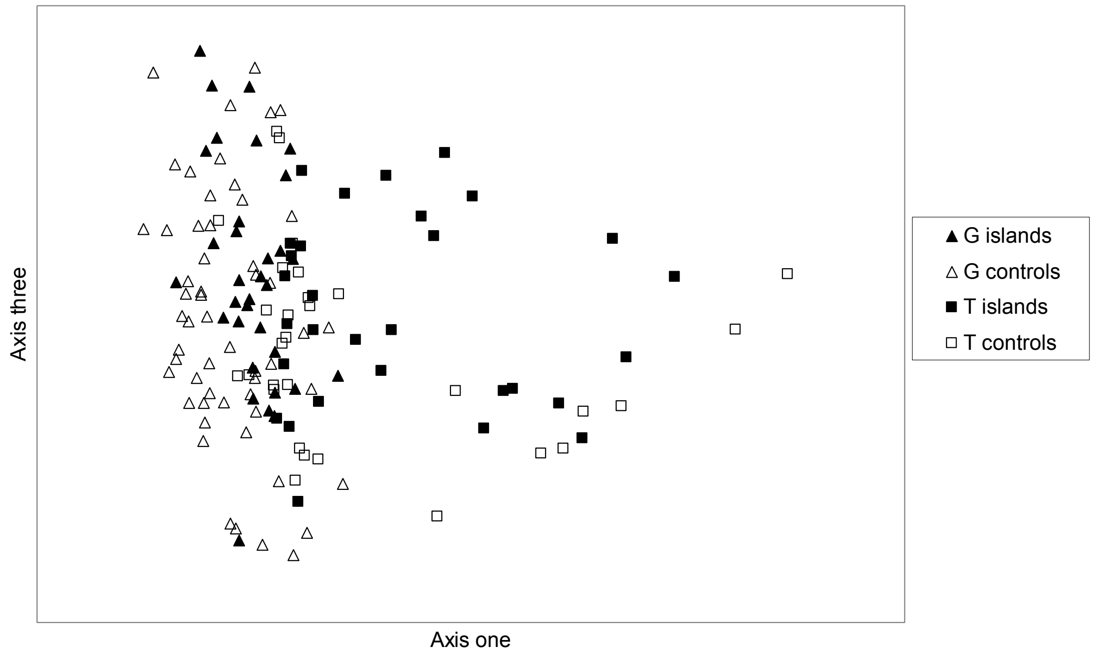


Figure 5.3b. Ordination plot (NMS, showing axis one versus axis three) for all the understorey island and control plots at all ages.

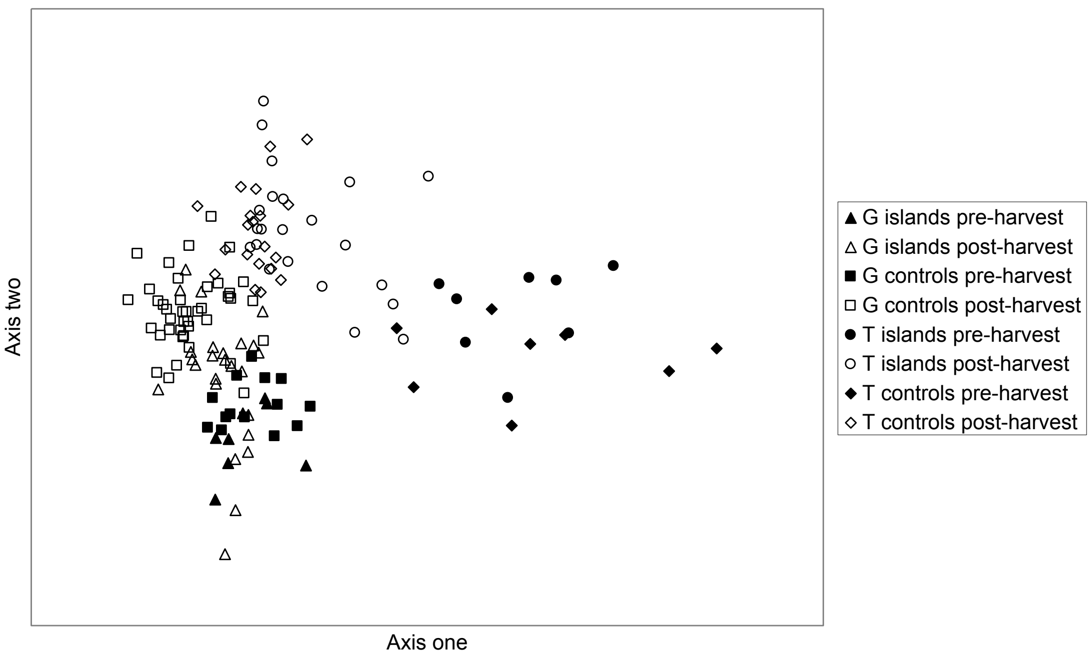


Figure 5.4a. Ordination plot (NMS, showing axis one versus axis two) for all the understorey islands and controls pre- and post-harvest.

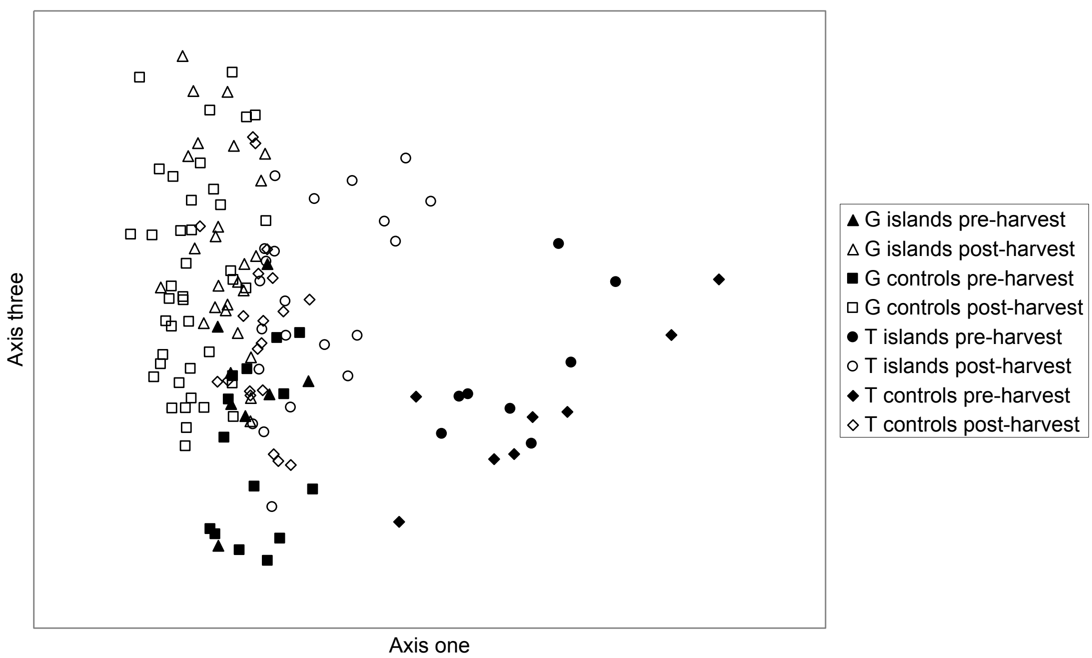


Figure 5.4b. Ordination plot (NMS, showing axis one versus axis three) for all the understorey islands and controls pre- and post-harvest.

Sclerophyll (G type) quadrats

The arrangement of all the G-type quadrats within the final ordination space at pre-harvest and at ages one, three and six years is shown in Figure 5.5. The quadrats within the one island that remained unburnt, 8B 193, have stayed in the same location within the ordination space throughout the sampling period (circled in Figure 5.5). The control quadrats and the disturbed island quadrats shifted away from the original ordination space at age one year. By age three years the control quadrats were still in a separate space whereas the islands were closer to the original ordination space. This was confirmed by the t-test which showed that the control quadrats had shifted significantly further in the ordination space at age three years than the island quadrats ($p = 0.0394$). At age six years, the island quadrats were again closer to the original ordination space whereas the control quadrats remain in a different space.

The ordination diagrams show that there is a difference in the floristic recovery of the disturbed (i.e. excluding the unburnt island) understorey island quadrats compared to the control quadrats. This difference was also evident in the TWINSPAN classification (Table 5.5). The first division of the TWINSPAN classification separated the pre-harvest quadrats from the age six year quadrats, except for the two unburnt quadrats which were retained with the pre-harvest set. Indicator species at this level are *Bauera rubioides*, *Nematolepis squarrosa* and *Pultenaea juniperina*. *Bauera* and *Nematolepis* were both ubiquitous and abundant pre-harvest and both were ubiquitous but less abundant post-harvest. *Pultenaea juniperina* was not recorded pre-harvest and was ubiquitous and abundant post-harvest in both the islands and the controls. At the second division, the post-harvest island quadrats are separated from the post-harvest controls. Indicator species at this level include *Melaleuca squarrosa* and *Gleichenia microcarpa*. Both species were more common in the islands than in the controls and both, along with *Blechnum wattsii*, which was also more common in the islands than in the controls, were observed to regenerate vegetatively. These three species are also identified in the summary table (Table 5.6) as the only ones to show a marked difference in cover-abundance in the island quadrats compared to the controls.

At age six years both the islands and controls were dominated by *Eucalyptus obliqua* over a shrub understorey dominated by *Acacia verticillata* and *Nematolepis squamea* over a dense sward of *Gahnia grandis, Pultenaea juniperina* and *Bauera rubioides*.

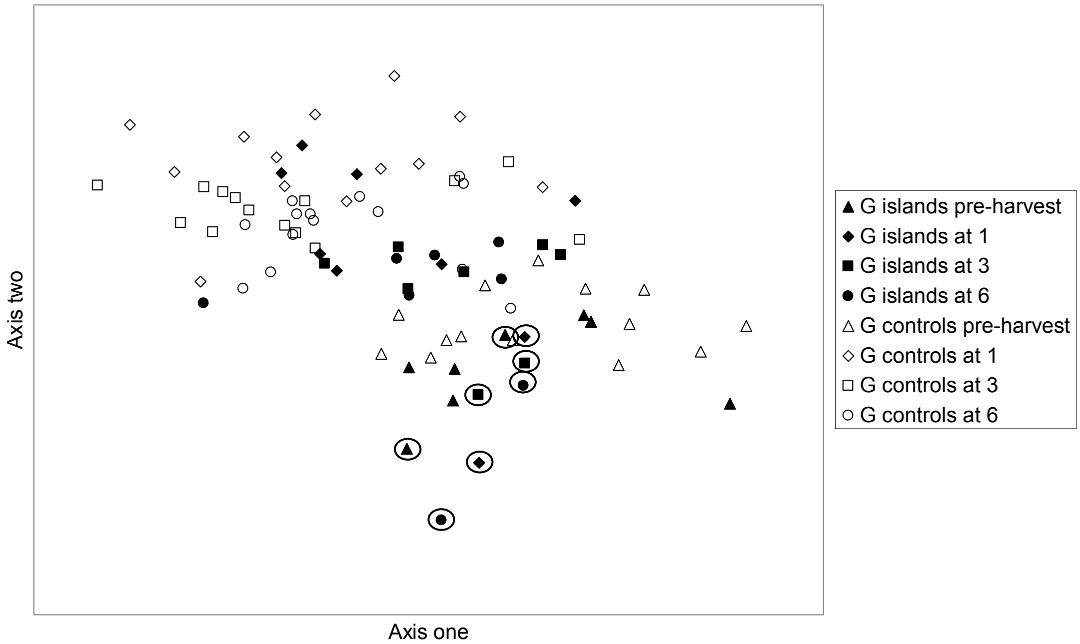


Figure 5.5a. Ordination plot (NMS, showing axis one versus axis two) for all the G type understorey islands and controls at all ages. The circled quadrats are those in understorey island 8B 193.

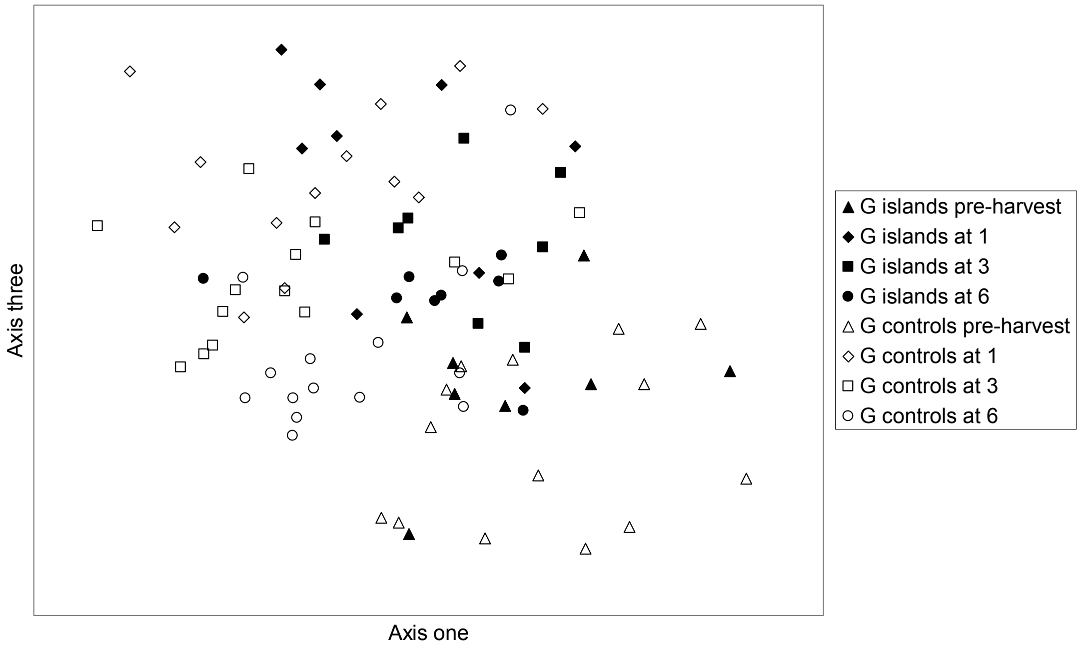


Figure 5.5b. Ordination plot (NMS, showing axis one versus axis three) for all the G type understorey islands and controls at all ages.

Table 5.5. TWINSPAN two-way table of species by quadrats for the G type understorey islands and controls. The quadrat numbers in bold at the top of the table show the eight island quadrats post-harvest. Species cover-abundances in bold show where those species were identified as indicators in the TWINSPAN classification. The vertical line (first division of the classification) separates the pre-harvest and unburnt quadrats (left) from the post-harvest quadrats (right).

```
                 12 1 111 114   11123 |222244223333333223344
                89065912650801273471934|253634490712348785612

 7  bankmarg    3---33344------2-------|-------11------------   0000
20  drymcyan    ---11---------1--------|---------------------   0000
24  galiaust    --1-----------------1--|---------------------   0000
29  grambill    -1--1----1-------------|---------------------   0000
33  hymepelt    --1-1----1-------------|---------------------   0000
55  tmesobli    --1--1----1------------|---------------------   0000
 1  acacia      ----1----------------11|---------------------   0001
 6  arispedu    11-1-2-1-1-1-121-11-111|---------------------   0001
18  corybas     -1111---------1-1--1-11|---------------------   0001
22  eucrluci    -------------2---------|---------------------   0001
 8  bauerubi    44443555433434444433343|21111-111-11321111121   0010
25  gleimicr    -2--11231-1--1121121231|1111111-1------------   0010
44  nemasqua    34444334342342333333--3|3-11-1111111111111111   0010
45  phylaspl    -1-1-----1---2-------1-|1--------------------   0010
54  tasmlanc    ----1-1----1-11--------|1--------------------   0010
11  blecwatt    -1-111--2-1112211121221|11--1-1-1------------   0011
12  caloelon    ------------1122--2-1-1|-1111-1-1------------   0011
41  melasqua    ----13---35233233233244|-1112111113----------   0011
14  cenaniti    ---------1--1----------|1--------------------   010
42  monoglau    1--33------32----------|1-----1-1--1--------1   010
46  pimedrup    --------111--1-------11|------1-1----1-------   010
17  corrlawr    ---2---------22--------|--1---1---------1----   011
21  eucaobli    455534543453443443-3-43|223333333434434333343   011
39  leptlani    333--323-33334333433433|333334344211-111-----   011
53  stictene    ------------------1----|1--------------------   011
 3  acacvert    --2323322322--32332----|3333223-1421334323333   10
23  gahngran    33333322243554345366534|655654433464344656555   10
47  polyprol    -1---------------------|-1-------------------   10
19  dickanta    ----------1------------|11-------------------   1100
35  isolepis    ---------------------11|-312--1--------1-----   1100
 4  acaenova    -----------------------|-1-------------------   1101
31  histinci    -----------------------|21--11---------------   1101
52  senemini    -----------------------|-1---1---------------   1101
28  gonoteuc    --1------------------1-|11----11--1--1-------   1110
40  leptscop    2----------------------|-1-1---1--111--------   1110
48  pomaapet    -33------2----2------32|-2221131---111123--43   1110
49  pterescu    --1--------------------|-------------------11   1110
 2  acacmela    -----------------------|----1------------1---   1111
10  billlong    -----------------------|1111111-11111--11--11   1111
13  casspube    -----------------------|-------1---111-------   1111
30  hibbempe    ----1----------------1-|1---1131111111113-111   1111
38  lepiensi    -----------------------|--1-------1-11--1--11   1111
43  oleastel    -----------------------|------1----1----1----   1111
51  pultjuni    -----------------------|1-1-113332334333312--   1111
56  violhede    -----------------------|-1-----1--1----------   1111

                00000000000000000000000|111111111111111111111
                00000000011111111111111|000000111111111111111
                00011111100000000000011|011111000011111111111
                   001111000011111111  | 01111    00000111111
```

Note. Full species names for the eight character abbreviations are listed in Appendix 4.1.

Table 5.6. Species mean cover and frequency of occurrence for all G type understorey islands

	Islands				Controls			
Time (years)	0		6		0		6	
	n = 8		n = 8		n = 14		n = 14	
	mean cover	frequency (%)	mean cover	frequency (%)	mean cover	frequency (%)	mean cover	frequency (%)
Group one	constant							
gahngran	4.63	100	4.25	100	3.07	100	4.86	100
eucaobli	2.88	88	2.75	88	4.07	100	3.29	100
leptlani	3.13	100	3.50	100	2.36	79	1.21	64
acacvert	1.50	63	1.38	63	2.00	79	2.86	100
corrlawr	0.50	25	0.25	25	0.14	7	0.07	7
monoglau	0.63	38	0.50	38	0.43	14	0.14	14
pimedrup	0.13	13	0.25	25	0.36	36	0.07	7
leptscop	0.25	13	0.13	13	0	0	0.36	36
histinci	0.25	13	0.25	25	0	0	0.07	7
Group two	decrease in controls over time							
melasqur	2.00	75	1.50	100	1.79	57	0.43	29
gleimicr	1.00	75	0.88	75	1.21	79	0.14	14
blecwatt	1.25	88	0.75	63	0.86	71	0.07	7
Group three	decrease in both islands and controls over time							
bauerubi	3.50	100	1.38	88	3.93	100	1.21	93
nemasqua	2.88	100	1.13	75	3.14	93	0.93	93
bankmarg	0.63	25	0.25	25	1.21	36	0	0
arispedu	0.88	75	0.13	13	0.64	57	0	0
corybas	0.25	25	0	0	0.50	50	0	0
phylaspl	0.38	25	0	0	0.29	29	0	0
tasmlanc	0.50	50	0	0	0.14	14	0	0
Group four	increase in both islands and controls over time							
pomaapet	0.25	13	1.00	63	0.93	36	1.43	71
pultjuni	0.13	13	1.50	75	0	0	1.93	71
hibbempe	0.13	13	0.88	63	0.14	14	0.93	79
caloelon	0.88	50	0.75	75	0.07	7	0.14	14
billlong	0.13	13	0.63	63	0	0	0.71	71
isolepis	0	0	0.25	25	0.14	14	0.43	21
gonoteuc	0.13	13	0.25	25	0.14	14	0.21	21
lepiensi	0	0	0.13	13	0	0	0.43	43
casspube	0	0	0.13	13	0	0	0.21	21

Note: **Group one** comprises those species whose cover and frequency have remained relatively constant over the sampling period, or where the species was recorded too infrequently to confidently ascribe a trend.
Group two comprises those species which have apparently declined over the sampling period in the controls but not in the understorey islands.
Group three comprises those species which have apparently decreased in both the islands and the controls over the sampling period.
Group four comprises those species which have apparently increased in both the islands and the controls over the sampling period.

Note. Full species names for the eight character abbreviations are listed in Appendix 4.1.

Thamnic (T type) quadrats

Figure 5.6 shows the T type understorey island and control quadrats pre-harvest and at ages one, three and six years. Post-harvesting, the island and control quadrats have shifted closer together in the ordination space; they are more similar to each other post-harvesting than they were pre-harvesting. At age six years all the island and control quadrats were very similar floristically (Figure 5.7). This was confirmed by the t-test, which revealed no significant difference in the change in distance within the ordination space between the island and control quadrats. There is one quadrat in the ordination space (8B 5 2, arrowed) that lies more or less between the pre-harvest quadrats and the age 6 year quadrats. A significant proportion of this quadrat was not burnt, and it was one of the few T type quadrats to retain a component of rainforest species at age six years.

The TWINSPAN classification of the T type quadrats from pre-harvesting and at age six years confirmed the above findings (Table 5.7). The first division in the classification (vertical line on table) separated the pre-harvest quadrats from the age six year quadrats. There were no further meaningful divisions. The only indicator species at the first division in the classification was *Grammitis billardierei*. *Grammitis billardierei* (finger fern) is a common epiphyte in rainforest understoreys; along with the other small epiphytic ferns it was not observed post-harvesting.

The summary table for the T type understorey islands (Table 5.8) also confirms these findings. There are no species that show a clearly different response in the islands as compared to the controls. One group of species, the epiphytic ferns, disappeared completely, the rainforest tree and shrub species have significantly reduced cover and abundance, and there was a wave of germination of sclerophyllous species. The epiphytic ferns, which were common throughout the rainforest quadrats (*Ctenopteris heterophylla*, *Grammitis billardierei*, *G. magellanica*, *Hymenophyllum australe*, *H. cupressiforme*, *H. peltatum*, *H. rarum*, *Rumohra adiantiformis* and *Tmesipteris obliqua*) are no longer present. Tree species absent from most of the rainforest quadrats at age six years include *Anodopetalum biglandulosum*, *Atherosperma moschatum*, *Eucryphia lucida* and *Phyllocladus aspleniifolius*. However, these species persisted, albeit at lower levels than pre-harvesting, in the two understorey islands in WR8B that had the lowest intensity burns, and scattered seedlings of

Phyllocladus were recorded in the burnt rainforest quadrats at age six years, so these quadrats are different to the controls. Shrub species that were absent from most of the rainforest quadrats at age six years include *Anodopetalum biglandulosum*, *Aristotelia peduncularis*, *Cenarrhenes nitida*, *Coprosma quadrifida* and *Tasmannia lanceolata*.

At age six years both the islands and controls were dominated by *Eucalyptus obliqua* over *Pomaderris apetala* and *Acacia verticillata* over a dense sward of *Gahnia grandis*.

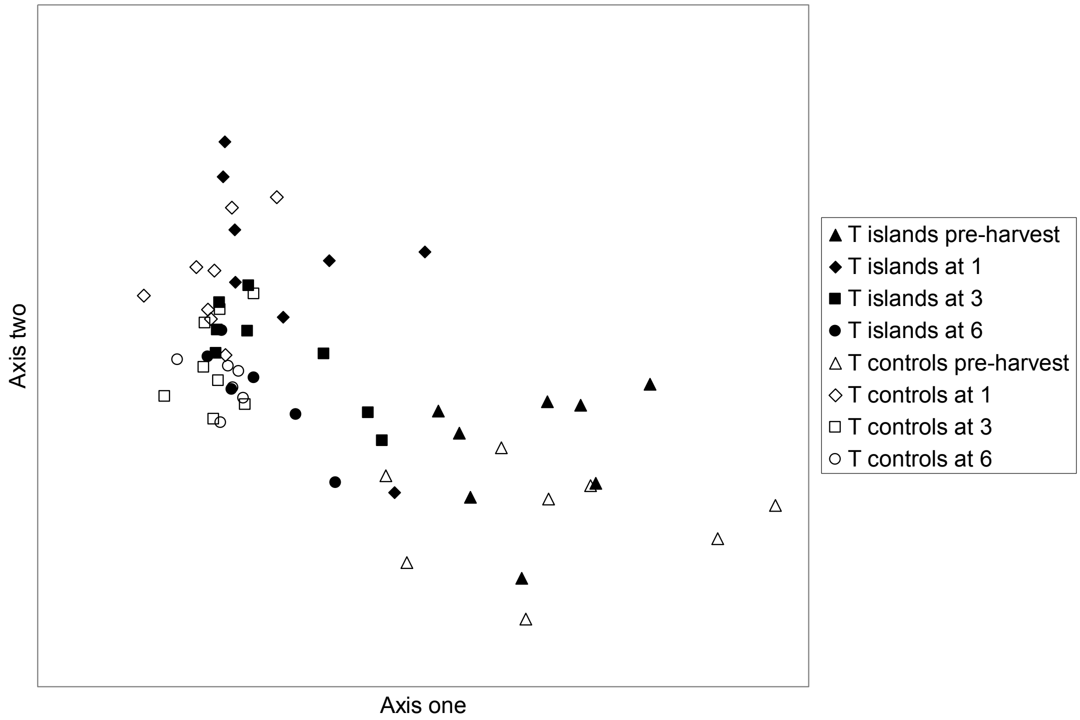


Figure 5.6a. Ordination plot (NMS, showing axis one versus axis two) for all the T type understorey islands and controls at all ages.

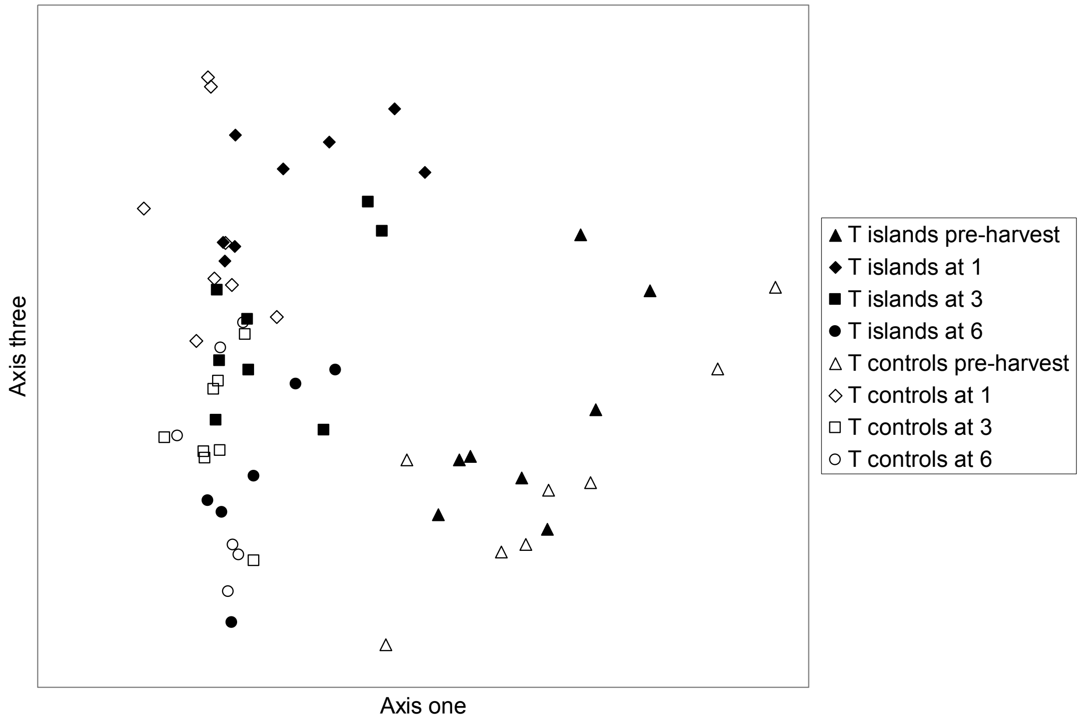


Figure 5.6b. Ordination plot (NMS, showing axis one versus axis three) for all the T type understorey islands and controls at all ages.

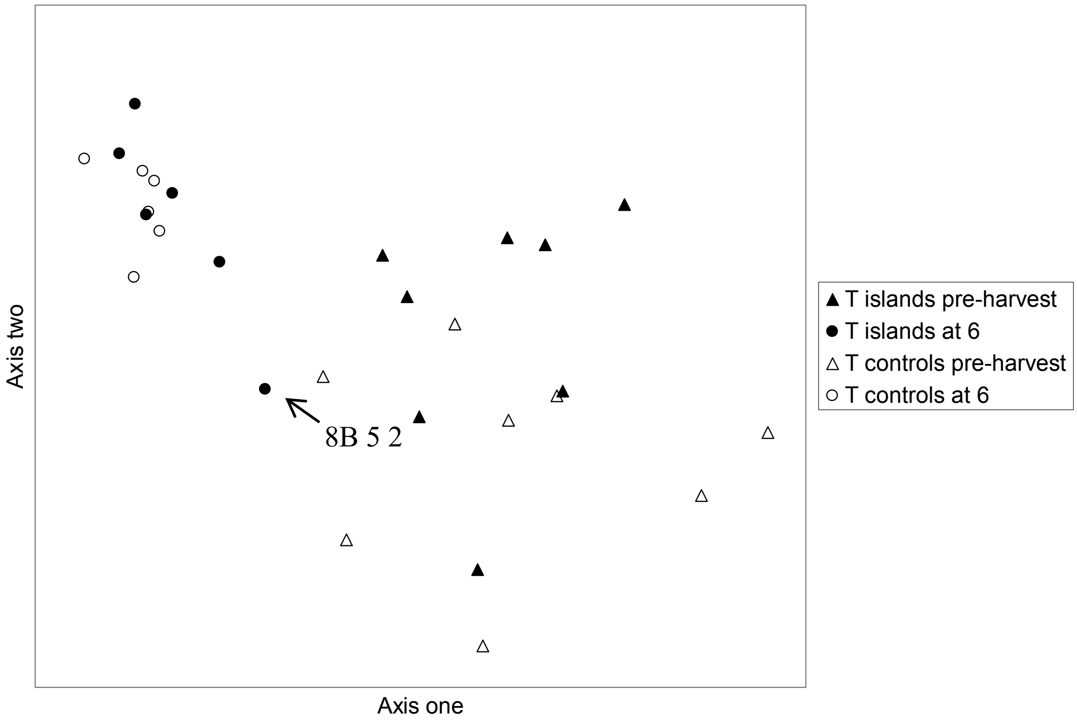


Figure 5.7a. Ordination plot (NMS, showing axis one versus axis two) for all the T type understorey island and controls pre-harvest and at age 6 years.

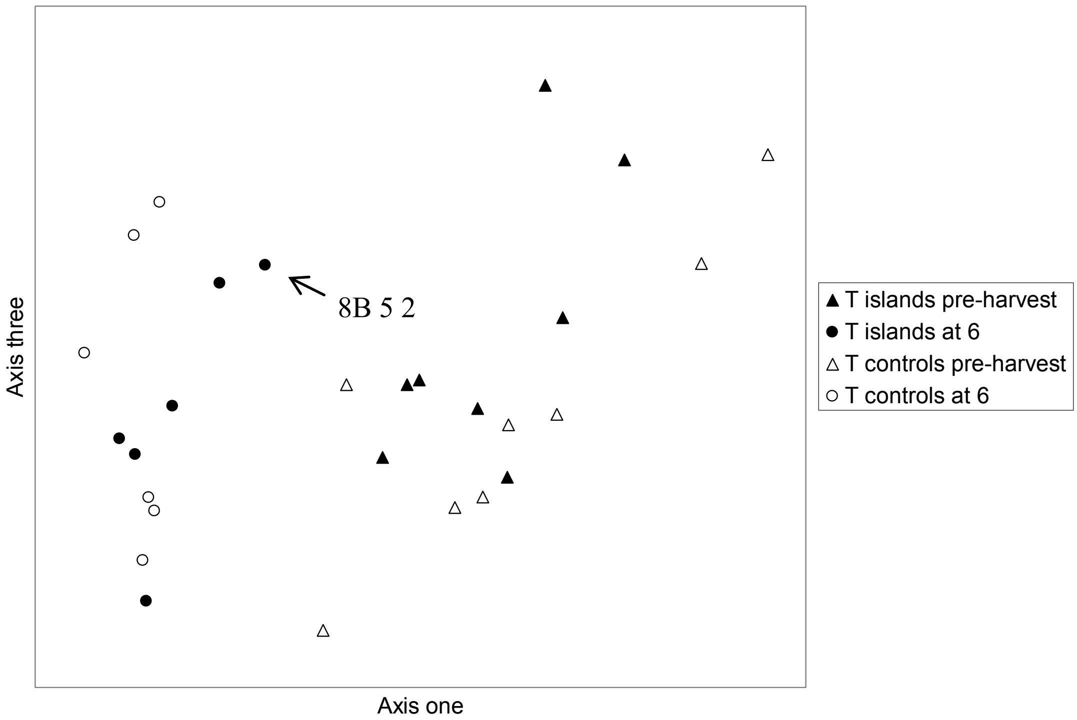


Figure 5.7b. Ordination plot (NMS, showing axis one versus axis three) for all the T type understorey island and controls pre-harvest and at age 6 years.

Table 5.7. TWINSPAN two-way table of species by quadrats for the T type understorey islands and controls. The quadrat numbers in bold at the top of the table show the islands quadrats post-harvest. Species cover-abundances in bold show where those species were identified as indicators in the TWINSPAN classification. The vertical line separates the pre-harvest and unburnt quadrats (left) from the post-harvest quadrats (right).

		111 1111	**222**2**12**222**2**11	
		3478903425612561	**712**5**90**346**8**78	
8	arispedu	----11-1---1-1-1	------------	0000
9	athemosc	3334-233-4333231	21----------	0000
24	eucrluci	3544-24443333344	41----------	0000
30	grammage	111-1111-----1--	------------	0000
48	phympust	---1--1---------	------------	0000
58	townsvir	11----1-1-----1-	------------	0000
6	anodbigl	4444665453-53432	11-1--------	0001
14	cenaniti	-2-2-12-22322231	1------1----	0001
19	ctenhete	1--1---1--1-11--	------------	0001
22	drymcyan	---11----1----11	------------	0001
29	**grambill**	**1111111111111111**	------------	**0001**
34	hymeaust	--1-11---------1	------------	0001
36	hymepelt	11------1--1-1-1	------------	0001
37	hymeraru	1111-1111111111-	------------	0001
12	blecwatt	11111-1111122111	1---------11	0010
16	coprquad	-12------22--1-1	--1---------	0010
26	gleimicr	----1------1----	1-----------	0010
47	phylaspl	-1-2122-33313333	11-1-----1--	0010
18	corybas	-----------111--	------------	0011
7	anopglan	--22------------	------------	010
35	hymecupr	1--1--------1---	------------	010
44	nothcunn	--44-------1----	------------	010
52	rumoadia	1111---------1-1	------------	010
15	clemaris	-1-1------------	----1-------	011
20	cyatglau	--------2-----11	111----11---	100
21	dickanta	11-------------1	-1----1-----	100
23	eucaobli	-3--322345-35323	233333444433	100
55	tasmlanc	11------1---2111	111--11-1---	100
2	acacmela	------33-----2--	-111111111--	101
46	nemasqua	----333-------2-	1111--11-111	101
10	bauerubi	-----2---------2	-111------11	1100
33	histinci	11--------------	1311-----1--	1100
49	pimedrup	111-------------	11111---11--	1100
25	gahngran	------1-2-222223	33232333442-	1101
41	leptlani	---------------2	3-----------	1101
43	monoglau	------2-------22	122-11122111	1101
51	pomaapet	2---2---233-42-2	334444444332	1101
59	troccunn	-------------1--	-------1-1--	1101
1	acacdeal	----------------	2-12----3---	1110
3	acacvern	----------------	--1---------	1110
4	acacvert	----2-------222-	322345124434	1110
5	agrostis	----------------	---1--------	1110
31	hibbempe	----------------	-11111-1----	1110
53	senemini	----------------	---1--1-----	1110
11	billlong	----------------	-1-1-1--1-11	1111
		0000000000000000	111111111111	
		0000111111111111	011111111111	
		000011111111	00011111111	
		00000001	00000011	

Note. Full species names for the eight character abbreviations are listed in Appendix 4.1.

Table 5.8. Species mean cover and frequency of occurrence for all T type understorey islands

	Islands				Controls			
Time (years)	0		6		0		6	
	n = 8		n = 8		n = 8		n = 6	
	mean cover	frequency (%)	mean cover	frequency (%)	mean cover	frequency (%)	mean cover	frequency (%)
Group one	constant							
tasmlanc	0.75	63	0.67	67	0.25	25	0.33	33
bauerubi	0	0	0.33	33	0.50	25	0.50	50
leptlani	0	0	0.50	17	0.25	13	0	0
dickanta	0.25	25	0.17	17	0.13	13	0.17	17
troccunn	0.13	13	0.17	17	0	0	0.17	17
gleimicr	0.13	13	0.17	17	0.13	13	0	0
clemaris	0.13	13	0.17	17	0.13	13	0	0
Group two	decrease in controls over time							
hymeaust	0	0	0	0	0.50	50	0	0
anopglan	0	0	0	0	0.50	25	0	0
Group three	decrease in both islands and controls over time							
anodbigl	3.25	88	0.33	33	4.50	100	0.17	17
eucrluci	3.38	100	0.83	33	3.25	88	0	0
athemosc	3.00	100	0.50	33	2.00	75	0	0
phylaspl	2.13	88	0.50	50	1.63	75	0.17	17
cenaniti	2.00	88	0.17	17	1.00	63	0.17	17
blecwatt	1.25	100	0.17	17	0.88	88	0.33	33
grambill	1.00	100	0	0	1.00	100	0	0
hymeraru	1.00	100	0	0	0.75	75	0	0
coprquad	0.75	50	0.17	17	0.38	25	0	0
nothcunn	0.13	13	0	0	1	25	0	0
grammage	0.38	38	0	0	0.63	63	0	0
arispedu	0.25	25	0	0	0.50	50	0	0
hymepelt	0.50	50	0	0	0.25	25	0	0
ctenhete	0.50	50	0	0	0.25	25	0	0
rumoadia	0.38	38	0	0	0.38	38	0	0
drymcyan	0.25	25	0	0	0.38	38	0	0
townsvir	0.38	38	0	0	0.25	25	0	0
corybas	0.38	38	0	0	0	0	0	0
hymecupr	0.25	25	0	0	0.13	13	0	0
Group four	increase in both islands and controls over time							
eucaobli	2.63	75	3.00	100	2.13	75	3.50	100
pomaapet	1.75	63	3.50	100	0.75	38	3.50	100
gahngran	1.25	63	2.83	100	0.75	38	2.50	83
acacvert	0.75	38	3.33	100	0.25	13	2.83	100
monoglau	0.25	13	1.33	100	0.50	25	1.17	83
nemasqua	0.25	13	0.67	67	1.13	38	0.83	83
acacmela	0.25	13	0.83	83	0.75	25	0.67	67
pimedrup	0.25	25	0.83	83	0.13	13	0.33	33
histinci	0.25	25	1.00	67	0	0	0.17	17
acacdeal	0	0	0.50	33	0	0	0.83	33
cyatglau	0.13	13	0.50	50	0.38	25	0.33	33
hibbempe	0	0	0.67	67	0	0	0.33	33
billlong	0	0	0.33	33	0	0	0.67	67

Note. Groups as Table 5.6

Note. Full species names for the eight character abbreviations are listed in Appendix 4.1.

Structural ordinations

There was a significant reduction in stress from the one dimensional (35) to the two-dimensional (19) and again to the three-dimensional result (13) but not to the fourth (9), which suggests that the data are three-dimensional (Figure 5.8).

When overlain by vegetation type, the ordination shows a clear separation of the G type understorey island and control quadrats and the T type understorey island and control quadrats (Figure 5.9, only the first two axes are shown). The G type vegetation typically comprises a moderately dense ground layer of *Gahnia grandis* and *Bauera rubioides*, beneath a dense tall shrub layer of *Leptospermum lanigerum*, *Melaleuca squarrosa, Nematolepis squamea* and *Acacia verticillata*, that forms a clear mid-canopy layer about 8 to 12 m high, beneath a sparser *Eucalyptus obliqua* overstorey. The T type understoreys are less obviously layered. The ground cover, excluding bryophytes which are often abundant is generally sparser and the shrub layers less clearly defined. This is also evident in Table 5.9; the ground layer cover in the T type island and control quadrats is consistently lower than in G type quadrats.

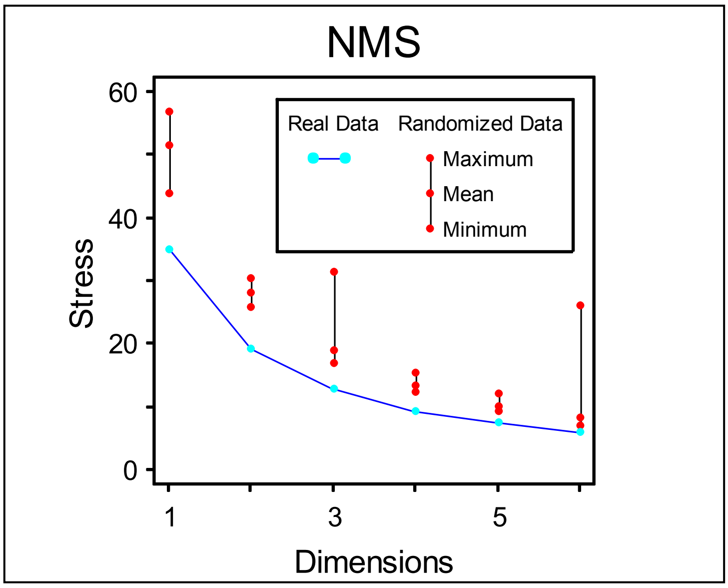


Figure 5.8. Stress plot (scree plot) for the NMS in Figure 5.9.

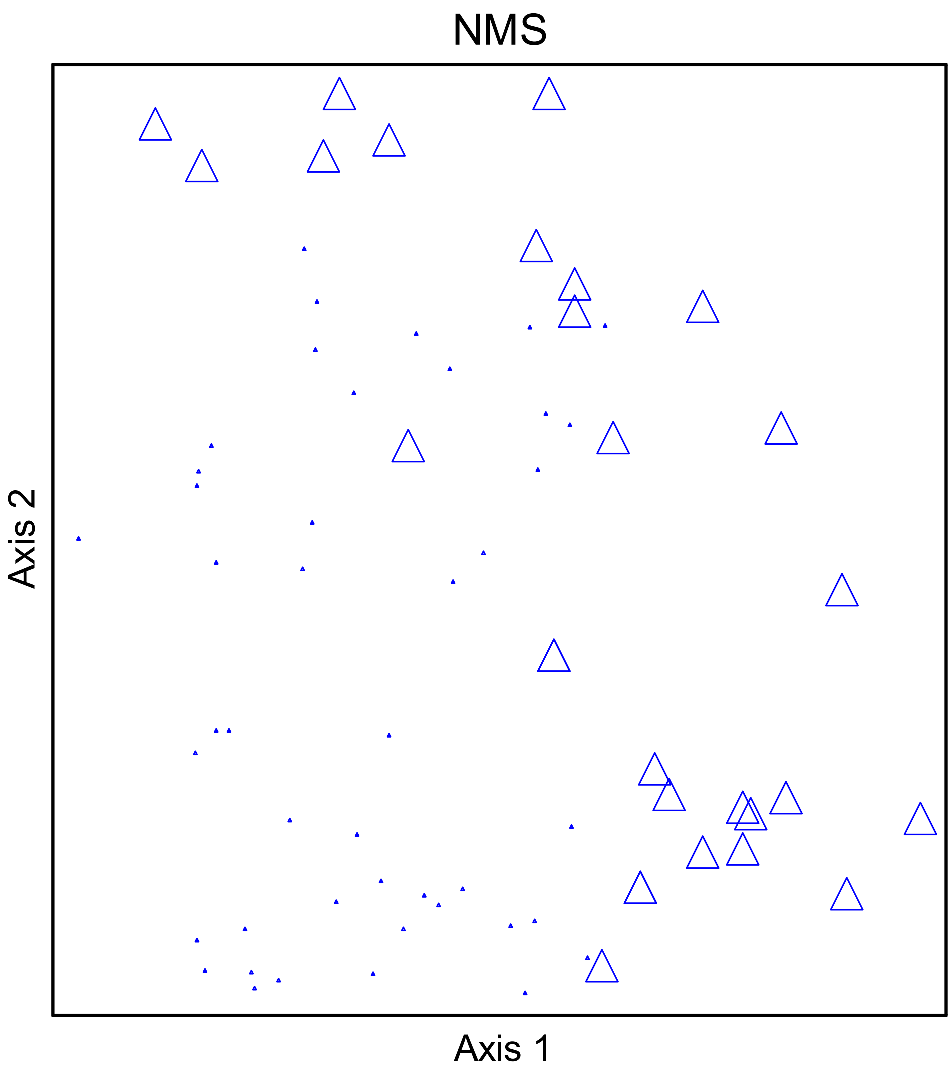


Figure 5.9. Non-metric multidimensional scaling ordination of the understorey island and their control quadrats based on the structural data at ages 0 and 6. The points labelled with small triangles are G type islands or controls, large triangles are T type islands or controls.

Table 5.9. Cover-abundance (%) of the vegetation within each height class, all islands and controls, pre-harvest.

	Island Type		Height class							
Plot number	Under-storey type[1]	Island or Control	Ground layer[2] to 1 m	Shrubs < 1 m	Shrubs 1 to 2 m	Shrubs 2 to 5 m	Trees 5 to 10 m	Trees 10 to 20 m	Trees 20 to 30 m	Trees 30 to 40 m
8H 13 1	T	Island	1	5	10	15	15	25	35	0
8H 13 2	T	Island	1	3	5	10	10	20	80	15
8H 16 1	T	Island	1	3	5	10	25	50	55	50
8H 16 2	T	Island	2	2	8	15	20	30	50	0
8B 7 1	T	Island	1	1	2	8	20	90	2	5
8B 7 2	T	Island	2	1	3	5	45	45	0	2
8B 5 1	T	Island	5	2	3	30	50	15	10	0
8B 5 2	T	Island	5	2	5	10	20	70	65	0
8H 106 1	G	Island	25	1	25	25	35	0	40	0
8H 106 2	G	Island	10	1	5	15	20	30	10	0
8H 40S 1	G	Island	28	2	15	2	4	15	20	15
8H 40S 2	G	Island	8	8	25	20	25	20	45	0
8B 193 1	G	Island	85	1	5	20	25	0	0	0
8B 193 2	G	Island	50	1	3	25	30	0	5	5
8B 68 1	G	Island	80	0	1	5	15	55	15	15
8B 68 2	G	Island	85	0	10	8	40	0	2	0
8H 9 1	T	Control	1	5	15	20	20	30	75	0
8H 9 2	T	Control	1	5	5	25	15	10	75	0
8H 12 1	T	Control	20	10	5	10	20	20	15	0
8H 12 2	T	Control	1	5	3	15	30	90	0	35
8B 4 1	T	Control	1	1	1	80	30	20	15	0
8B 4 2	T	Control	1	1	10	80	15	8	3	0
8B 6 1	T	Control	2	1	5	20	55	15	70	5
8B 6 2	T	Control	1	1	5	5	10	25	50	5
8H 234 1	G	Control	20	10	45	5	15	55	30	0
8H 234 2	G	Control	26	1	15	6	3	60	15	0
8H 264 1	G	Control	40	1	15	10	40	15	20	15
8H 264 2	G	Control	10	3	15	2	50	10	15	45
8H 418 1	G	Control	10	20	30	20	65	15	20	0
8H 418 2	G	Control	20	2	15	3	15	80	75	0
8H 518 1	G	Control	3	15	25	15	20	20	55	15
8H 518 2	G	Control	2	15	35	15	70	10	25	0
8B 124 1	G	Control	50	0	5	10	70	0	30	0
8B 124 2	G	Control	15	0	20	0	10	40	25	0
8B 232 1	G	Control	15	5	20	15	10	50	3	65
8B 232 2	G	Control	20	3	25	10	8	45	0	60
8B 130 1	G	Control	15	1	3	5	75	10	20	0
8B 130 2	G	Control	4	5	25	15	55	0	0	20

Note 1. Understorey type; T = Thamnic type, G = Gahnia type.

Note 2. Ground layer includes sedges and ground ferns, which were recorded separately to shrubs in the same height class.

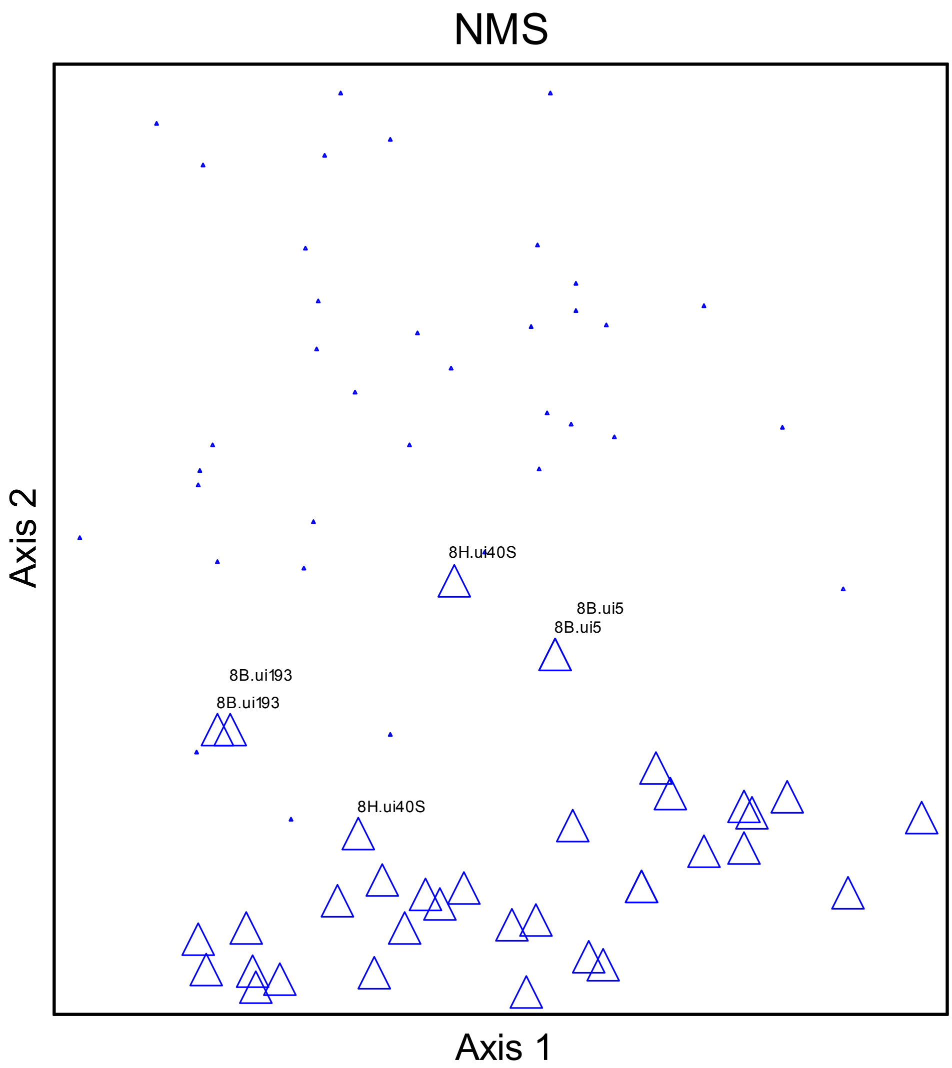


Figure 5.10. Non-metric multidimensional scaling ordination of the understorey island and their respective control quadrats based on the structural data at ages 0 and 6. The points labelled with small triangles are those at age 0, large triangles are those at age 6.

Table 5.10. Cover-abundance (%) of the vegetation within each height class, all islands and controls, at age 6 years.

	Island Type		Height class							
Plot number	Under-storey type[1]	Island or Control	Ground layer[2] to 1 m	Shrubs < 1 m	Shrubs 1 to 2 m	Shrubs 2 to 5 m	Trees 5 to 10 m	Trees 10 to 20 m	Trees 20 to 30 m	Trees 30 to 40 m
8H 13 1	T	Island	2	5	25	40	0	0	0	0
8H 13 2	T	Island	15	2	10	60	2	0	0	0
8H 16 1	T	Island	8	7	5	16	0	0	0	0
8H 16 2	T	Island	2	18	30	20	0	0	0	0
8B 7 1	T	Island	26	5	10	50	0	0	0	0
8B 7 2	T	Island	26	5	10	50	0	0	0	0
8B 5 1	T	Island	25	8	15	40	15	20	0	0
8B 5 2	T	Island	25	8	15	40	15	20	0	0
8H 106 1	G	Island	55	10	30	28	0	0	0	0
8H 106 2	G	Island	45	20	30	30	0	0	0	0
8H 40S 1	G	Island	12	45	22	3	0	0	23	0
8H 40S 2	G	Island	16	1	35	5	0	1	0	0
8B 193 1	G	Island	55	1	20	2	40	0	0	0
8B 193 2	G	Island	55	1	8	3	38	0	0	0
8B 68 1	G	Island	60	0	5	25	0	0	0	0
8B 68 2	G	Island	40	1	5	60	0	0	0	0
8H 9 1	T	Control	6	1	1	35	0	0	0	0
8H 9 2	T	Control	6	12	22	25	0	0	0	0
8H 12 1	T	Control	2	10	2	65	0	0	0	0
8H 12 2	T	Control	1	16	30	38	0	0	0	0
8B 4 1	T	Control	15	3	20	60	0	0	0	0
8B 4 2	T	Control	35	2	2	50	0	0	0	0
8B 6 1[3]	T	Control								
8B 6 2	T	Control								
8H 234 1	G	Control	84	1	5	18	0	0	0	0
8H 234 2	G	Control	91	1	8	12	0	0	0	0
8H 264 1	G	Control	76	2	18	12	0	0	0	0
8H 264 2	G	Control	60	8	22	16	0	0	0	0
8H 418 1	G	Control	78	2	15	7	0	0	0	0
8H 418 2	G	Control	48	4	12	27	0	0	0	0
8H 518 1	G	Control	45	3	23	18	0	0	0	0
8H 518 2	G	Control	18	20	40	30	0	0	0	0
8B 124 1	G	Control	82	2	4	15	0	0	0	0
8B 124 2	G	Control	65	1	4	12	0	0	0	0
8B 232 1	G	Control	50	4	0	50	0	0	0	0
8B 232 2	G	Control	70	3	25	35	0	0	0	0
8B 130 1	G	Control	45	0	15	45	0	0	0	0
8B 130 2	G	Control	40	1	10	40	0	0	0	0

Notes: 1. Understorey type; T = Thamnic type, G = Gahnia type.
2. Ground layer includes sedges and ground ferns, which were recorded separately to shrubs in the same height class.
3. Island 8B 6 was not assessed for structure at age 6, and islands 8B 7 and 5 were assessed as one quadrat each rather than as two separate quadrats.

When overlaid by time, the ordination of the structural data shows that three understorey islands at age six years are distinct from the remaining islands and controls at that time (Figure 5.10, again, only the first two axes are shown). UI 193 is the only island that remained unburnt at the completion of burning. UI 5 retained a green core at the completion of burning and there has been some coppicing of the rainforest species, and UI 40S (quadrat 1 in particular) contained a number of retained eucalypts and despite being burnt by a high intensity fire, these eucalypts have produced epicormic shoots at age six years (Photo 5.3 – taken at age 1 year). Structurally these three islands at age six years are distinct from the other islands and the controls. Again, this is also evident in Table 5.10, where the three above mentioned islands are the only ones to have any cover recorded in the > 5 m height classes. Many of the other islands retain some structural elements but as they are standing dead, having been killed by the heat of the regeneration burn, they were not recorded at the post-burn remeasurements.

Photo 5.3. Understorey island 8H 40S, about one year after the regeneration burn.

Regression

The multiple regression analysis (Table 5.11) showed that there was a significant relationship between the change in the floristics of each quadrat from pre-harvest to year 6, as measured by change in Euclidean distance in the ordination space, and the extent of oxidised soil in the quadrat. Unburnt quadrats have retained most of their pre-harvest vegetation intact, whilst the hottest burnt islands have lost all their pre-harvest vegetation.

Table 5.11. Multiple regression analysis of the Euclidean distance between each plot from pre-harvest to age six years, against the cover-abundance of each seedbed class as recorded immediately after the regeneration burn.

Dependent variable: Change in Euclidean distance from pre-harvest to age six years

Parameter	Estimate	Standard Error	T Statistic	p-value
Constant	0.312033	0.185613	1.68109	0.1039
Ashbed (B2) cover-abundance	0.319669	0.0710056	4.50203	0.0001

Analysis of variance

Source	Sum of squares	Degrees of freedom	Mean square	F-ratio	p-value
Model	5.657084	1	5.65784	20.27	0.0001
Residual	7.81612	28	0.279147		
Total (corr.)	13.474	29			

R-squared = 41.99%

R-squared (adjusted for degrees of freedom) = 39.92%

Standard error of estimate = 0.528344

Mean absolute error = 0.36748

Durbin-Watson statistic = 1.44593

Discussion

This study found that maintaining areas of the understorey undisturbed by harvesting in both understorey types during the harvesting and burning operations enhanced their floristic and structural diversity following the disturbance. To some extent, this was found to be the case even where the understorey islands had been burnt during the regeneration burn.

There were no operational difficulties reported in retaining the islands undisturbed by machinery during the course of the harvesting. The harvesting contractors described working around the islands as being similar to working around streamside reserves, and at the conclusion of harvesting mechanical damage to the understorey islands was negligible. Mechanical disturbance to the controls in this study was also limited, but this was more by chance than management as the controls were not marked on the ground so that the contractor did not know where they were.

It became apparent during the harvesting, and more particularly during the burning, that it was important not to locate the understorey islands too close to the harvesting boundary. This allowed sufficient space for safe working. Sufficient space is also essential to allow safe lighting of the harvesting debris during the regeneration burn. As it is hoped that plant species retained intact within the islands will contribute propagules to assist more rapid recolonisation of the harvested area in the future, it also makes ecological sense to have the islands scattered throughout this area. Exposure of the islands to prevailing winds and the relative risk of windthrow will also need to be taken into consideration.

The floristic response of the understorey islands demonstrated that by retaining even small areas of understorey undisturbed it is possible to increase the within-coupe floristic diversity post-harvest, although the intensity of the regeneration burn within the islands had a significant influence on their ultimate usefulness for retaining floristic values. Those islands which burnt at highest intensity retained the fewest floristic elements, and those which burnt at lowest intensity retained the most. In wet eucalypt forests in Victoria Ough and Murphy (1998) observed significantly higher survival rates of resprouting species within understorey islands than in areas routinely harvested. They found that the significant floristic differences between the understorey islands and their respective controls arose almost entirely as a result of enhanced vegetative recovery.

In the sclerophyll islands in this study, resprouting occurred from protected underground rhizomes and rootstocks. In the rainforest islands, resprouting also occurred from protected underground rhizomes and rootstocks, and also via epicormic shoot development on retained stems. Hickey (1994) has shown that most common rainforest species are present in regenerated mixed forest following clearfelling, burning and sowing, but that the frequency of occurrence of epiphytic ferns declines. In this study, epiphytic ferns were common in the rainforest quadrats prior to harvesting and burning, but were not observed post-disturbance. Occasional coppice and seedling regeneration of rainforest species were observed throughout the coupe post-disturbance, and it is also expected that there will be some rainforest species regeneration within the coupe arising from seed dispersed from trees in the adjacent unharvested areas (Tabor *et al.* 2007). The islands did not contribute towards maintenance of the epiphytic flora within the coupe. This is almost certainly related to the small size of the islands.

The islands carried some structural elements into the regenerating stand, but their small size meant they were vulnerable to windthrow where exposed to prevailing winds, and difficult to protect during the regeneration burn. Maintaining stand structural complexity within harvested and regenerated forests is a key part of sustainable forest management (Lindenmayer and Franklin 2002). However, the amount of in-coupe structural retention achieved by the understorey islands in this study was very small. At age six years some of the islands cannot be perceived from the road as they are no taller than the surrounding regeneration. Whilst the contractor had the option of harvesting the eucalypts from the understorey islands where that could be done without damaging the islands, in a number of instances the contractor left the eucalypts standing. The standing eucalypts make a significant contribution to the retained structural diversity, however, they were all burnt during the regeneration burn and standing burnt trees are more vulnerable to collapse than unburnt trees (Gibbons *et al.* 2000; Whitford and Williams 2001), due to hollowing out of their bases by fire. The rates of loss are low (less than 2% per year, op. cit.), so some of the retained trees can be expected to contribute to the structural diversity of the stand for some decades yet.

Currently in Tasmania coupes are often cull felled and/or scrub rolled at the conclusion of harvesting, in the belief that this will contribute to an even regeneration burn across the coupe. But the evidence presented here suggests that within-coupe floristic and structural diversity can be increased by leaving all the culls and otherwise undisturbed areas of the understorey intact wherever safe and practical to do so within the coupe. However, this may have some significant costs. The regeneration burn may not be as hot, as some of the understorey will still be green when the regeneration burn is lit, and will not burn as well as would dry fuels. A lower intensity burn may lead to a reduced area of receptive seedbed, resulting in lower stockings of eucalypts (chapter 7). Fires may be harder to manage as the fuel will not be as combustible, and standing dead trees may prove an impediment to aerial ignition by helicopter, as well as to future intensive stand management such as thinning.

The evidence presented here also indicates that where it is desirable to retain elements of the pre-harvesting stand into the regenerating stand, then larger areas of retention will be necessary. These should be more windfirm, and more defensible during the regeneration burning. Such an approach was explored in the aggregated retention and stripfell treatments, which are the subject of the next chapter.

Chapter 6. Structural responses of the retained trees, belts and aggregates.

Introduction

In most clearfell, burn and sow (CBS) coupes all the trees are felled (Hickey and Wilkinson 1999a); the consequent regeneration is essentially even-aged and there is little structural diversity in the regenerating stand. Critics of the CBS system point to the lack of structural diversity in the regenerating stand as one of the key features that distinguishes CBS regeneration from that following natural disturbance (Franklin *et al.* 1997; Lindenmayer and McCarthy 2002). The most common natural disturbance event in wet eucalypt forest is wildfire, and while wildfires may kill some of the standing trees, stand-replacing wildfires in wet eucalypt forest are rare and many of the large old trees survive into the regenerating stand (Lindenmayer *et al.* 2000; Turner *et al.* 2008). Consequently, stands regenerating following wildfires usually have greater structural diversity than those following CBS operations.

Retaining greater local structural diversity is important to maintaining structural, functional and compositional diversity in the post-disturbance regenerating stand (Franklin *et al.* 1997; Spies 1998; Franklin *et al.* 2002; Lindenmayer and McCarthy 2002). Large old trees are commonly identified as one of the most important structural features, whether they are standing alive or dead, or fallen (Franklin *et al.* 1997). Standing they are important as den and nest sites for both vertebrates and invertebrates (Gibbons and Lindenmayer 2002) and fallen they are hosts to a wide range of invertebrates (Harmon *et al.* 1986; Laudenslayer *et al.* 1999; Grove and Meggs 2003) and fungi (Norden *et al.* 2004; Yee *et al.* 2006).

Retaining individuals or groups of trees into the regenerating stand has become one of the goals of variable retention operations throughout the world (e. g. Franklin *et al.* 1997; Fries *et al.* 1997; Mitchell and Beese 2002; Martinez Pastur *et al.* 2009; Forestry Tasmania 2009b). Franklin *et al.* (1997) identified three major purposes of this retention: lifeboating, where the retained trees or groups of trees carry elements of the pre-harvest stand into the regenerating stand, enriched structural diversity, and landscape connectivity. None of these purposes can be achieved if the integrity of the retained groups is destroyed shortly after their isolation during the harvesting by the combined effects of exposure, windthrow and fire.

Edges created during harvesting are susceptible to damage from the harvesting, and from the increased exposure to wind and sun. In southern Tasmania, prevailing winds are from the northwest (Bureau of Meteorology 2009) and the afternoon sun is also in the northwest quadrant, so edges that face northwest are more susceptible to drying and windthrow than other edges (Parry 1997), which in turn leaves these edges more vulnerable during the regeneration burning. Westphalen (2003) has shown that edge effects in wet eucalypt forests in southern Tasmania with respect to changes in average daily maximum temperature and vapour pressure deficit, are limited to 10 m from created edges; changes in photosynthetically active radiation could be detected up to 50 m from created edges.

The heavy fuel loads created during the harvesting operation need to be removed in order to reveal mineral soil seedbed and the most economical and effective method is fire (Shea *et al.* 1981). The standard approach following clearfelling in wet eucalypt forests for many years has been a high intensity burn, featuring a strong central convection column that draws the outside edges of the fire inwards thus minimising the risk of escapes into adjacent unharvested forest. In order to maintain the retained trees and groups of trees unburnt a different approach to burning is required. Planned burns must be of lower intensity, whilst still aiming to reduce the post-harvesting fuel loads (Chuter 2007). However, during the regeneration burning there is always a risk that retention will be burnt. Burnt oldgrowth trees are more likely to die and/or collapse more quickly than unburnt trees (Whitford and Williams 2001; Neyland 2004; Gibbons *et al.* 2008).

Post-harvest windthrow is recognised world-wide as a significant cause of loss of retained trees where alternative silvicultural systems have been tested (e.g. Coutts and Grace 1995; Ruel 2000; Scott and Mitchell 2005; Wood *et al.* 2008). Retained trees should provide a more enduring ecological benefit if they remain alive and upright than if windthrown, although it is recognised that as coarse woody debris on the ground they also provide habitat (Grove and Meggs 2003). Windthrown sections of forest, where that windthrow has occurred between the completion of harvesting and the regeneration burn, also appear to be at greater risk of burning during the regeneration burn.

In the Warra silvicultural systems trial (SST) structural elements from the pre-harvest stand were retained into the post-harvest stand in all of the treatments. Planned retention levels ranged from less than 5% of the harvested area in CBS with understorey islands, to over 70% in the group selection treatment. In the CBS with understorey islands and the dispersed and aggregated retention treatments, the intention was to maintain retained trees or groups of trees for the duration of the planned rotation. In the stripfells and patchfell, the intention was to maintain the retained groups for at least half the duration of the planned rotation, that is at least 45 years, in order to provide a source of propagules of later successional species into the regenerating stands. In the group selection treatments, a series of small cuts was planned over a much longer rotation, with some permanent retention.

This chapter focusses on the two treatments in which there was significant retention within the harvest boundary: the aggregated retention treatment, in which about 30% of the planned harvest area was retained as aggregates of about half to one hectare, and the stripfells and patchfell, in which about half of the planned harvest areas was retained as belts about two tree heights wide between harvested strips of similar width, the patchfell being a little wider. Monitoring of harvesting damage, the impact of the regeneration burn, and windthrow was undertaken within these treatments, to assess the short term impacts of the harvesting and regeneration activities on the retention and to assess the probability of the retained elements persisting over time.

Hickey (1994) has shown that all of the vascular species typical of wet eucalypt forest are present in regenerating forest at similar frequencies as observed pre-harvesting. However, Hickey (1994) also noted that species more typical of later successional stages were sometimes present at lower frequency in the regenerating forest than pre-disturbance and suggested that rotation length may be a more important factor in determining the perpetuation of mixed forest than the regeneration treatment. Tabor *et al.* (2007) have shown that the recruitment of the dominant rainforest understorey tree species is enhanced close to mixed forest edges. One of the aims of retaining aggregates or strips in mixed forest is to enhance the recruitment of the rainforest species, under the assumption that this will increase the rate at which mixed forest redevelops. Mixed forest in the SST occurred only in the upper sections of the stripfell treatment; monitoring in that treatment was focussed on the mixed forest sections.

The study tested the following hypothesis;

- Retention of unharvested forest, as strips or aggregates, within the harvest boundary increases the post-harvest structural diversity within the harvested coupe.

Methods

Stripfells and patchfell (WR1A) monitoring

The harvesting, by cable, of the stripfells and patchfell (WR1A) was completed in June 1999. The harvesting created two retained 'belts' of vegetation ('W' (western) and 'E' (eastern)) and two north-south trending edges ('G' (for Grant Westphalen (Westphalen 2003), and 'B' (bank)) (Figure 6.1). By chance, as their orientation for harvesting purposes was perpendicular to the slope, the belts were also oriented more or less perpendicular to the prevailing wind. The forest to the south of the southern edges of the strips and patchfell graded quickly into buttongrass plain and scrub. These edges were not considered susceptible to windthrow due to the nature of the vegetation and being parallel to the prevailing wind, and were not monitored.

Eight permanent monitoring transects were established within WR1A (Figure 6.1). Random number tables were used to determine the distance down from Manuka Road to the take-off point for each transect, which was laid out perpendicular to the edge from which it was established. The location of the transects was constrained because the area immediately below Manuka Road that had been disturbed during the original road construction was excluded. The southern part of the coupe where the understorey was dominated by sclerophyllous shrubs was also excluded. The regeneration and persistence of the mixed forest elements present in this coupe were of particular interest with respect to the establishment of this treatment, so the transects were deliberately located within the mixed forest.

Each 10 m wide transect was located using GPS and map and compass surveys. Stakes were used to mark the centreline. The species, diameter at breast height over bark (dbhob), health, damage to and cause of damage, and x - y co-ordinates of each tree with a dbhob of at least 10.0 cm, were recorded. The height at which the diameter of each tree was measured was marked with paint.

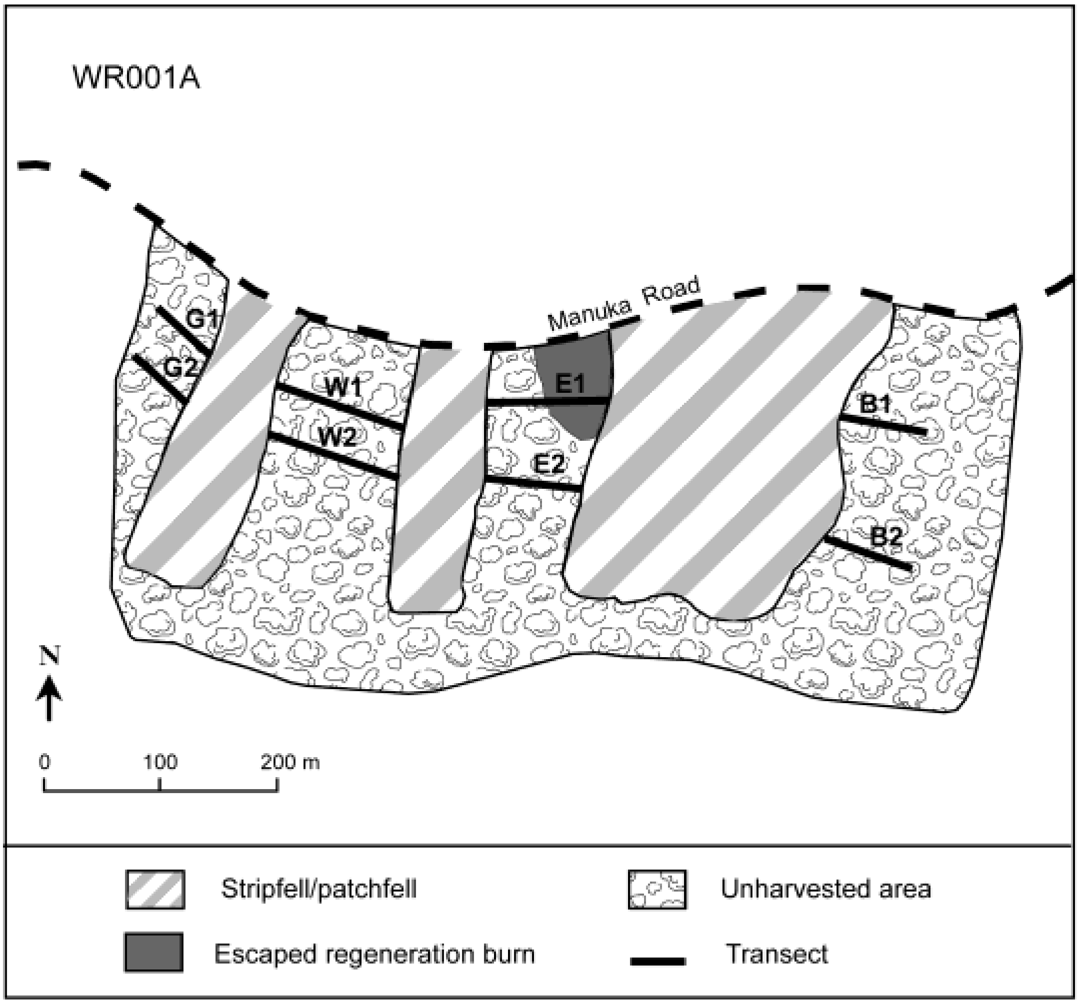


Figure 6.1. The layout of WR1A at the completion of harvesting, and the location of the permanent monitoring transects. The two stripfells are the harvested sections to the left of centre, the patchfell is the larger harvested section to the right of centre.

The transects were established and assessed in November 1999, after the completion of harvesting but before burning. The moderate intensity regeneration burn was completed in March and April 2000 (see Chapter 2 for details). A minor incursion of the regeneration burn across transect E1 was mapped shortly after the burn. The burnt section of the transect was surveyed and each uniform area of seedbed was allocated to unburnt, burnt to litter, burnt to mineral soil or ashbed. The transects were remeasured four and nine years after establishment. The basal area (m^2 ha^{-1}) at establishment and at the final measurement was calculated for each species within each transect, for each species across all eight transects, for each transect, and for the coupe. The proportional contribution of each species towards the total loss of basal area across all transects and species between 1999 and 2008 was also calculated. This was used to determine which species were the major contributors to the net basal area loss over that time.

Aggregates and coupe edge monitoring (WR1E and WR8I)

Harvesting of the aggregated retention coupes was completed in late 2003. In both coupes, close to 30% of the planned coupe area was retained in evenly dispersed aggregates that ranged in size from about one-quarter to one hectare.

After the completion of harvesting and prior to burning, all trees within 10 m of the harvest boundary in all the aggregates and around the coupe edges, hereafter referred to as edge trees, were examined for harvesting damage. Each separate incident of damage to any tree that resulted in exposure of the cambium to the air was recorded, regardless of how minor, as any exposure is considered to render the tree susceptible to subsequent entry of decay causing organisms (Wardlaw 1996). The physical location of the damage (bark, roots or crown) was also recorded.

The coupes were burnt by a low-intensity regeneration burn in April 2004 (see Chapter 2). After the completion of burning, all the coupe and aggregate edges were re-examined and the areal extent of any burning within the aggregates was mapped. The degree of scorch to the crown of the trees within 10 m of an edge was recorded as none; up to one-third of the crown scorched; one-third to two-thirds of the crown scorched; or greater than two-thirds of the crown scorched. No burning extended further than 10 m into an aggregate or coupe edge. The degree of burning of the bark of each burnt tree was recorded as: light, burning confined to the lower metre of the trunk; moderate, burning extended above one metre but the entire trunk was not burnt or; severe, the majority of the fine bark consumed.

Aggregate health transects (WR1E and 8I)

To monitor the longer-term health of the vegetation within the aggregates, permanent transects were established in three randomly selected aggregates in each of the aggregated retention coupes. Two transects were established within each aggregate, one running north-south, and one running east-west (Figures 6.2 and 6.3). Each transect was 10 m wide. The species, health, damage to and cause of damage, and x - y co-ordinates of each tree with a diameter at breast height over bark of at least 10 cm was recorded. Only the major occurrence of damage was recorded for each tree; e.g. for a tree with a major branch broken out of the crown during harvesting, and minor rub marks on the bark caused by an adjacent tree, only the crown break would be recorded. The transects were established after completion of harvesting in late 2003. They were reassessed shortly after the regeneration burn in June 2004, and again three years later in June 2007.

The relationships between the extent of windthrow and burning within each aggregate and the size of that aggregate were explored using simple linear regression. The proportion of windthrown trees was regressed against the distance from the edge of the aggregate.

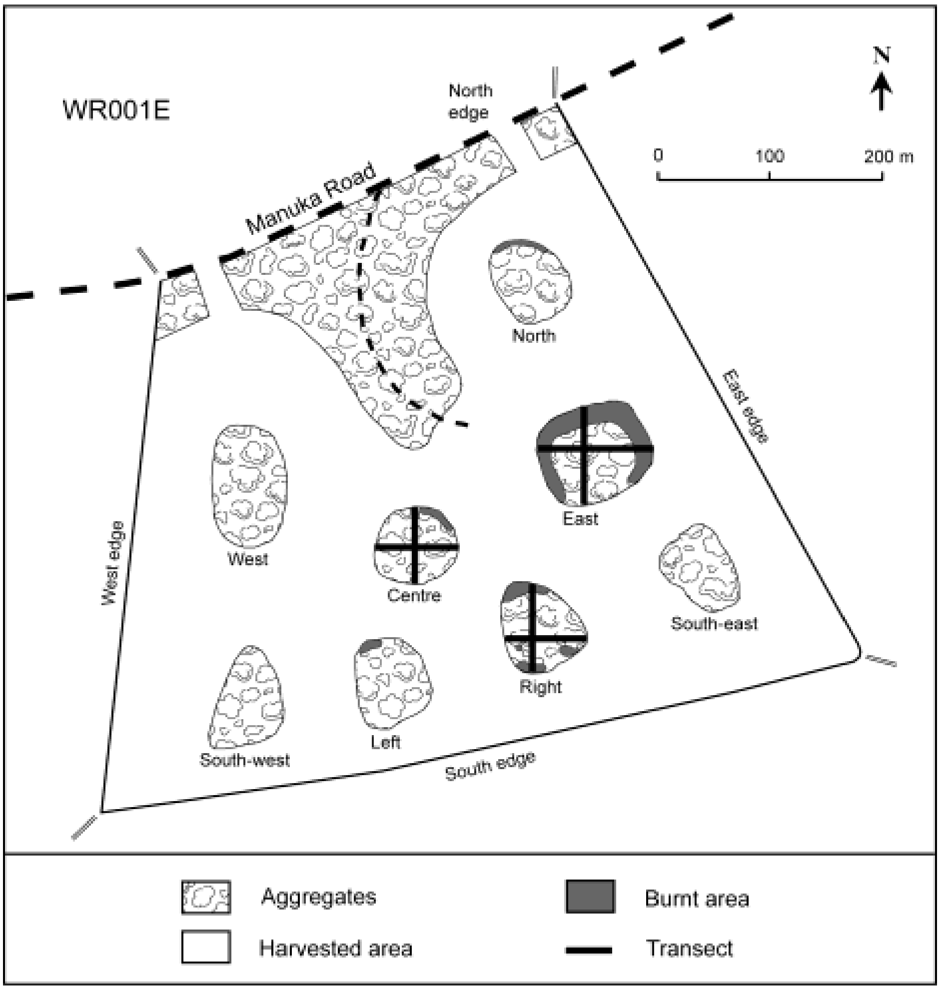


Figure 6.2. The layout of WR1E at the completion of harvesting, and the location of the permanent monitoring transects.

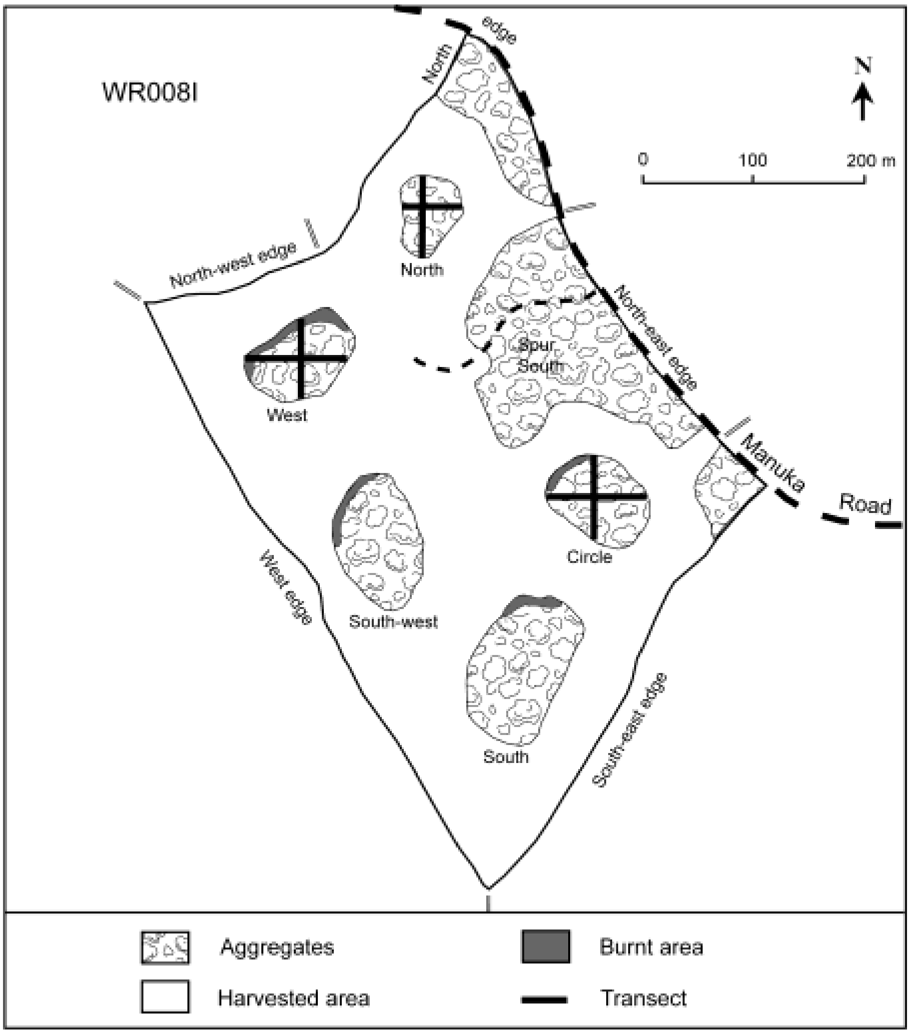


Figure 6.3. The layout of WR8I at the completion of harvesting, and the location of the permanent monitoring transects.

Results

WR1A, Stripfells and patchfell, immediately post-harvesting, harvesting damage

Harvesting damage to the retained trees in WR1A was very limited. Of the 516 trees assessed within the transects at the completion of harvesting (data not shown), just six had minor scrapes into the bark and five had lost major branches from the crown, generally as a result of being hit by a falling tree. One tree had lost all its crown and died.

WR1A, immediately post-burning, burning damage

Almost half (the eastern 49 of 106 m) of transect E1 had burnt (Figure 6.1), of which 6% was ashbed, 33% was burnt to mineral soil, 43% was burnt to litter, and 18% was unburnt. It was noted that a fibrous peat layer ranging from 10 to 50 cm depth overlaid much of the soil in the eastern belt. Where this peat layer had burnt, understorey shrubs that were rooted in it were wilting badly. There was no other burning damage within the coupe.

WR1A; four and nine years post-harvesting and burning, death, all causes

Four years after the completion of harvesting 18% of the stems or 15% of the basal area had died, including windthrow (Table 6.1). Five years later another 7% of the stems or 7% by basal area had died, which indicates that the rate of attrition had slowed.

Table 6.1. Changes in stem counts and basal area between measurements of the belt transects, WR1A.

Year	Total stem count	Loss[1] between measurements	Total basal area (m^2)	Loss between measurements
1999	540		61.9	
2003	445	95 (18%)	52.6	9.3 (15%)
2008	409	36 (7%)	48.4	4.2 (7%)

Note 1: 'Loss' is the loss compared to the 1999 count or basal area.

Within the burnt section of transect E1 one large oldgrowth eucalypt died. At the far western end of the same transect, another large oldgrowth eucalypt was windthrown across the transect, causing considerable physical damage to other trees on the transect. The loss of these two oldgrowth trees (Table 6.2) represented 75% of the total basal area loss across all transects in the first nine years after harvesting, but just 2% of the loss of stems (2 of 130, Table 6.3). The other significant species loss in the first nine years was myrtle (*Nothofagus cunninghamii*). About one-third (34%) of the original basal area of the myrtles was lost (Table 6.2) (or 38% by stem count, Table 6.3), predominantly to myrtle wilt, but also to the collapse of the afore-mentioned oldgrowth trees, windthrow and fire. The dead myrtles comprised a significant proportion (14%) of the overall loss in transect E1 (Table 6.2) but there were also occasional dead myrtles throughout the rest of the transects.

Table 6.2. Basal area (m^2 ha^{-1}) for 17 tree species on eight transects in WR1A measured in June 1999 and June 2008. Percentage loss (right hand column) is the proportional contribution of each species towards the total loss of basal area across all transects and species between 1999 and 2008.

	Year	G1	G2	W1	W2	E1	E2	B1	B2	Total	% Loss
Acacia melanoxylon											
	1999	5.96	6.21	–	4.43	3.62	6.39	–	1.25	27.86	
	2008	5.81	6.83	–	4.50	3.70	3.44	–	2.38	26.66	0.94
Acacia verticillata											
	1999	0.20	–	–	–	–	–	0.11	0.12	0.44	
	2008	0.00	–	–	–	–	–	0.00	0.00	0.00	0.34
Anodopetalum biglandulosum											
	1999	0.64	0.94	1.96	2.60	0.52	–	–	0.22	6.88	
	2008	0.71	0.68	1.40	1.86	0.00	–	–	0.27	4.94	1.53
Anopterus glandulosus											
	1999	–	–	–	0.09	–	–	–	–	0.09	
	2008	–	–	–	0.00	–	–	–	–	0.00	0.07
Atherosperma moschatum											
	1999	–	2.17	0.15	–	3.06	1.00	2.40	1.64	10.42	
	2008	–	1.80	0.16	–	1.60	0.00	2.58	1.87	8.00	1.90
Cenarrhenes nitida											
	1999	–	–	–	0.11	–	–	–	–	0.11	
	2008	–	–	–	0.11	–	–	–	–	0.11	0.00
Eucalyptus obliqua											
	1999	192.04	83.75	11.44	55.23	146.83	90.99	25.23	24.81	630.33	
	2008	196.62	87.75	12.37	61.08	43.50	82.90	25.91	27.12	537.24	73.19
Eucryphia lucida											
	1999	2.45	4.20	6.26	1.19	0.83	0.63	6.57	3.09	25.22	
	2008	2.16	4.06	6.83	1.44	0.59	0.13	5.23	3.30	23.74	1.16
Leptospermum lanigerum											
	1999	–	–	–	0.47	–	0.14	–	–	0.60	
	2008	–	–	–	0.43	–	0.15	–	–	0.58	0.02
Melaleuca squarrosa											
	1999	–	–	–	8.48	–	–	–	1.23	9.70	
	2008	–	–	–	8.81	–	–	–	0.63	9.44	0.21
Monotoca glauca											
	1999	0.29	–	–	0.23	–	–	–	–	0.52	
	2008	0.29	–	–	0.26	–	–	–	–	0.56	-0.03
Nematolepis squamea											
	1999	2.64	2.44	0.24	1.85	0.40	4.15	0.68	2.03	14.43	
	2008	1.77	1.25	0.27	1.26	0.43	1.89	0.88	1.05	8.80	4.43
Nothofagus cunninghamii											
	1999	7.55	14.10	15.29	6.33	4.28	0.15	14.76	4.41	66.87	
	2008	6.53	9.04	8.36	4.31	0.61	0.20	15.80	2.61	47.46	15.26
Phyllocladus aspleniifolius											
	1999	–	–	3.78	–	–	0.15	–	0.37	4.30	
	2008	–	–	1.75	–	–	0.22	–	0.49	2.48	1.43
Pittosporum bicolor											
	1999	–	–	0.18	–	–	–	–	0.25	0.43	
	2008	–	–	0.18	–	–	–	–	0.25	0.43	0.00
Pomaderris apetala											
	1999	–	–	–	–	3.17	2.93	0.13	1.56	7.79	
	2008	–	–	–	–	3.80	2.82	0.14	1.84	8.60	-0.64
Tasmannia lanceolata											
	1999	–	–	–	–	–	–	–	0.25	0.25	
	2008	–	–	–	–	–	–	–	0.00	0.00	0.20
Grand total	1999	211.77	113.80	39.29	81.00	162.71	106.52	49.88	41.24	806.22	
	2008	213.89	111.41	31.33	84.07	54.23	91.76	50.54	41.80	679.03	100.0
Total loss between 1999 and 2008 for all species on all transects										127.19	

Table 6.3. Counts of stems lost by species and by cause of death on eight transects in WR1A measured in June 1999 and June 2008.

				Cause of loss				
Species	Total count 1999	Losses to June 08	% loss	Wind throw	Smashed by downer	Fire	Unknown or as specified	Other causes and comments
Acacia melanoxylon	30	9	30	3	3	0	2	1 died from harvesting damage
Acacia verticillata	3	3	100	2	1	0	0	May have died of old age
Anodopetalum biglandulosum	40	14	35	1	1	3	9	4 windthrown stems still green
Anopterus glandulosus	1	1	100	1	0	0	0	
Atherosperma moschatum	21	9	43	1	1	4	3	
Cenarrhenes nitida	1	0	-	0	0	0	0	
Dicksonia antarctica	50	6	12	0	4	2	0	17 stems showing signs of sunburn
Eucalyptus obliqua	106	22	21	3	10	1	8	3 suppressed stems died naturally
Eucryphia lucida	85	12	14	5	3	2	2	6 windthrown stems still green
Leptospermum lanigerum	4	0	-	0	0	0	0	
Melaleuca squarrosa	31	2	6	0	0	0	1	1 killed after logging damage – top broken out
Monotoca glauca	3	0	-	0	0	0	0	
Nematolepis squamea	36	13	36	5	3	0	5	
Nothofagus cunninghamii	87	33	38	4	5	4	18	7 from wilt
Phyllocladus aspleniifolius	7	2	29	2	0	0	0	
Pittosporum bicolor	3	0	-	0	0	0	0	
Pomaderris apetala	31	3	10	3	0	0	0	4 windthrown stems still green
Tasmannia lanceolata	1	1	100	0	0	0	1	
Totals	540	130	24	29 (22%)[1]	31 (24%)	16 (12 %)	50 (38%)	4 (3%)

Note 1: Percentage loss is the loss compared to the 130 trees and shrubs lost overall.

By age nine years, all trees in the burnt section of transect E1 had died, with the exception of one small regrowth eucalypt, one *Acacia melanoxylon* and one tree fern. This was the most extensive loss within WR1A. The only species to record an increment in basal area over the sampling period was dogwood (*Pomaderris apetala*), a broad-leaved understorey species that is often common in early successional-phase forests (Table 6.2). The overall loss of stems, 24% by count or 22% by basal area (Table 6.3) is significant but includes a number of trees, for example very suppressed eucalypt regrowth stems, that would have died naturally. All the dead prickly wattles (*Acacia verticillata*) were considered to have reached natural senescence.

WR1E and WR8I, aggregated retention, immediately post-harvesting, harvesting damage

Across both aggregated retention coupes (WR1E and WR8I) the net damage to trees retained on coupe and/or aggregate edges was 11% (85 damaged trees of 783 monitored, Table 6.4a and 6.4b). Most of the damage was to the lower trunk and roots of trees on edges of the aggregates, where they had been struck by logs or machinery either during the harvesting or during the firebreaking. There was very little crown damage.

WR1E and WR8I, burning damage – coupe and aggregate edges

The regeneration burns in the aggregated retention coupes were designed to be low intensity and this outcome was achieved (Chapter 2). There were no escapes from the regeneration burns into the adjacent unharvested forest. In both coupes 11% by area of the aggregates was burnt (Table 6.5 and see Figures 6.2 and 6.3), although there was a large degree of variation between the individual aggregates, ranging from no area burnt in a number of aggregates to 38% by area in 'right' aggregate in WR1E. The burnt areas in all aggregates except 'right' aggregate are on the sides that are exposed to the prevailing north-westerly winds and afternoon sun.

Table 6.4a. Damage to eucalypts in the aggregates and edges (n) (WR1E), after harvesting and firebreaking.

	Aggregate[1]								Edge section				Total
	South-east	East	Right	Centre	North	West	South-west	Left	North	East	South	West	
Type of damage[2]													
Bark	3	3	3	2	2	1	1	1	2	1	1	0	20
Root	0	2	1	1	2	3	2	2	6	0	1	4	24
Crown	0	0	0	0	0	0	1	0	0	0	0	0	1
Total tree count	17	31	36	42	18	34	26	49	62	32	63	41	451
Total damaged trees	3	4	4	3	2	4	4	3	4	7	1	1	40
Percentage of trees damaged	18	13	11	7	11	12	16	6	6	22	2	3	9
Perimeter or section length (m)	260	326	240	252	267	282	248	300	400	490	658	437	4160

Table 6.4b. Damage to eucalypts in the aggregates and edges (n) (WR8I) after harvesting and firebreaking.

	Aggregate					Edge section					Total
	Circle	South	South-west	West	North	North	North-east	South-east	West	North-west	
Type of damage											
Bark	0	4	1	8	0	7	1	1	5	2	29
Root	0	2	1	7	0	2	0	1	1	0	14
Crown	0	1	0	2	0	0	0	2	4	0	9
Total tree count	45	36	18	41	13	52	16	32	56	23	332
Total damaged trees	0	6	2	13	0	8	1	4	8	2	45
Percentage of trees damaged	0	17	11	32	0	15	6	12	14	9	14
Perimeter or section length (m)	265	357	336	266	128	460	296	470	613	162	3353

Notes: 1. Aggregate names and edge section labels are shown in Figures 6.2 and 6.3.
2. In both tables, the incidence of damage is not additive as some trees were damaged twice; for example in aggregate WR1E North two trees were damaged; both had both bark and root damage.

Table 6.5. Area burnt and the number and percentage of windthrown stems in the six intensively monitored aggregates compared in June 2004 and June 2007.

	Number of stems									
	East–West transect			North–South transect			Both transects			
Aggregate	Total 2004	Wind-thrown 2004	Wind-thrown 2007	Total 2004	Wind-thrown 2004	Wind-thrown 2007	Total 2004	Wind-thrown 2004	Wind-thrown 2007	Per cent of area burnt
WR1E										
Centre	115	0	14	66	5	12	181	5	26	7
		-	12%		8%	18%		3%	14%	
East	118	21	55	90	2	18	208	27	73	33
		25%	47%		2%	20%		13%	36%	
Right	57	4	20	75	4	43	132	6	63	38
		2%	35%		5%	57%		5%	48%	
WR8I										
North	41	0	0	82	1	1	123	1	1	0
		-	-		1%	1%		1%	1%	
West	53	15	19	57	0	8	110	8	27	21
		8%	36%		-	14%		7%	25%	
Circle	98	2	11	49	3	10	147	5	21	3
		2%	11%		6%	20%		3%	14%	

WR1E and WR8I, burning damage to retained trees – coupe and aggregate edges

Four trees outside the harvested area in WR8I were scorched; this was the only impact of the burn outside the coupe. In WR1E nothing outside the harvested area was burnt or scorched. Within the aggregates in both coupes most trees (87%) remained unburnt and unscorched. Most of the trees that were burnt or scorched were within those areas of the aggregates that had ground fires within them, but there were also occasional trees within aggregates that were scorched by the heat of the fire in the adjacent harvested areas.

WR1E and WR8I, Aggregate transects

Within the aggregate transects, windthrow was evident when the transects were first established in the first winter after the completion of harvesting, especially in WR1E (Table 6.6), and continued over time. At the post-burning assessment, it was not always possible to determine whether the trees were

Table 6.6a. Damage by type, all species, all trees greater than 10 cm dbhob, aggregated retention coupes, (% of total number of stems within each coupe; WR1E, n = 521 stems, WR8I, n = 380).

		Type								
Coupe	Year	Wind throw	Burnt, light to moderate	Burnt, severe	Standing dead	Crown branch loss	Bark break	Scarring	Total damaged	Undamaged
WR1E	2003	10.7	0.0	0.0	1.0	4.8	1.3	1.2	19.0	81
	2004	11.5	5.6	8.1	0.6	3.8	1.0	0.8	31.3	68.7
	2007	19.2	0.0	3.6	10.6	7.9	2.1	2.3	45.7	54.3
WR8I	2003	0.3	0.0	0.0	0.8	0.5	0.0	1.3	2.8	97.2
	2004	3.1	2.8	1.3	0.8	0.5	0.3	0.5	9.2	90.8
	2007	9.2	–	–	5.6	3.1	4.6	2.3	24.9	75.1
Both	2003	6.3	0.0	0.0	0.9	3.0	0.8	1.2	12.2	87.8
	2004	8.0	4.4	5.2	0.7	2.4	0.7	0.7	22.1	77.9
	2007	15.1	–	2.1	8.5	5.9	3.2	2.3	37.2	62.8

Table 6.6b. Damage by cause, all species, all trees greater than 10 cm dbhob, aggregated retention coupes (%).

		Type								
Coupe	Year	Wind	Downer	Unknown (dead)	Unknown (damaged)	Logging	Rubbing	Fire	Total damaged	Undam-aged
WR1E	2003	12.7	1.7	1.0	2.3	0.4	1.0	0.0	19.0	81
	2004	12.9	1.7	0.6	1.7	0.0	0.8	13.6	31.3	68.7
	2007	17.9	4.4	14.2	3.5	0.2	1.9	3.6	45.7	54.3
WR8I	2003	0.8	0.3	0.8	0.0	0.0	1.0	0.0	2.8	97.2
	2004	3.6	0.3	0.8	0.0	0.0	0.3	4.4	9.2	90.8
	2007	6.7	6.7	5.6	2.1	0.0	3.6	0.3	24.9	75.1
Both	2003	7.7	1.1	0.9	1.3	0.2	1.0	0.0	12.2	87.8
	2004	9.0	1.1	0.7	1.0	0.0	0.6	9.8	22.1	77.9
	2007	13.2	5.4	10.7	2.9	0.1	2.7	2.2	37.2	62.8

windthrown because they were burnt, or burnt because they were windthrown. When trees were observed to be dead in 2007, the cause of death could not always be confidently attributed to the regeneration burn. For example, burnt bark often falls off *Eucalyptus obliqua* regrowth after the tree has died, so by the time of this later assessment the tree can be standing dead with no apparent burning damage. While it may be reasonable to assume that burning damage contributed to the death of the tree, this cannot be stated for certain. In 2004, fire was the leading cause of damage in WR1E with 13.6% of stems damaged by fire and 12.9% by wind (Table 6.6). In 2007 wind was the leading cause of damage (17.9%); 14.2% of stems were damaged by causes unknown. As explained above, much of this damage was probably by fire. The leading causes of damage and death remain wind and fire. 'Downer' damage is physical damage caused by windthrow of neighbouring stems, so this again is wind-derived.

WR1E and WR8I, windthrow and death over the next three years

There was a strong relationship between the extent of burning within each aggregate at age zero years and the extent of windthrow at age three years (Figure 6.4, Table 6.6), although this relationship was derived from the monitoring of just six aggregates. By age three years, it was clear that windthrow and burning damage are linked. The worst affected aggregate within the SST was 'right' aggregate in WR1E that was 38% burnt by area and 48% windthrown by stems counts. This aggregate was longer north-south than east-west and there was a long fetch. The harvested area to the immediate west of this aggregate extended for a considerable distance, and was subject to the strong westerly winds that accompany cold fronts in this area. On the ground this aggregate was clearly the most physically disturbed of the aggregates. No relationship could be discerned between the extent of burning or windthrow, and the size of the aggregate. This is possibly because other factors, such as fetch, are involved. In both coupes small aggregates that were close to the western boundary were largely unaffected by windthrow. For example, one of the smallest aggregates is 'north' aggregate in WR8I; this aggregate is located in a relatively sheltered position and damage was negligible .

It is also apparent (Table 6.5) that there has been ongoing windthrow between the 2004 and 2007 assessments. The majority of the damaged stems in both coupes were understorey shrubs (Table 6.7). It was evident when assessing the transects that the understorey suffers a domino effect to some extent. Collapse of the understorey often commenced on the western extremity of the aggregate and gradually extended further into the aggregate. Ongoing monitoring will be necessary to determine the duration of this effect and whether or not the understorey eventually stabilises.

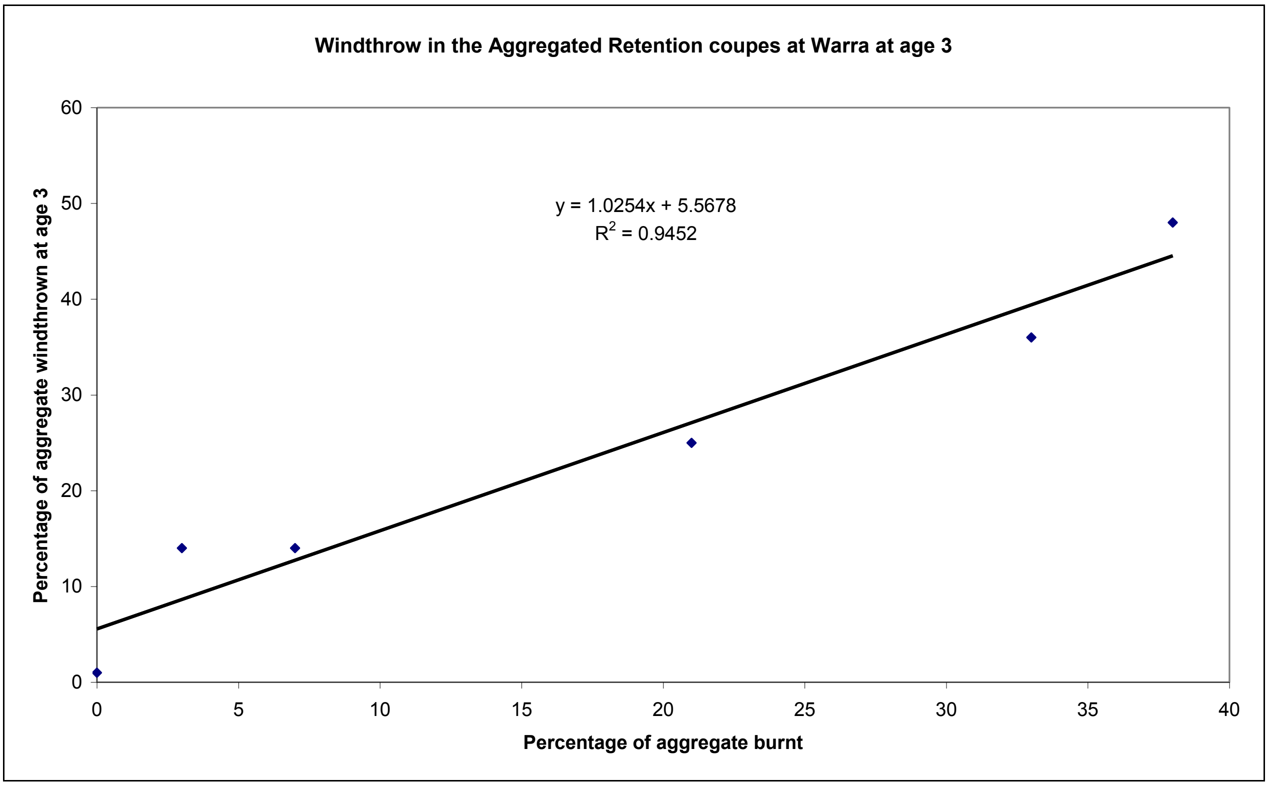


Figure 6.4. Regression of percentage of windthrown stems at age 3 years against percentage of aggregate burnt in WR1E and WR8I.

Table 6.6. The percentage of area burnt and the percentage of windthrown stems (all species, stems greater than 10 cm dbhob) in the six intensively monitored aggregates in June 2007.

		east-west transect			north-south transect			total		
Aggregate	% of area burnt	wind thrown stems	total stems	%	wind thrown stems	total stems	%	wind thrown stems	total stems	%
WR1E Centre	7	14	115	12	12	66	18	26	181	14
WR1E East	33	55	118	47	18	90	20	73	208	35
WR1E Right	38	20	57	35	43	75	57	63	132	48
WR8I North	0	0	41	–	1	82	1	1	123	1
WR8I West	21	19	53	36	8	57	14	27	110	25
WR8I Circle	4	11	98	11	10	49	20	21	147	14

Table 6.7a. The percentage of damaged stems on the aggregate transects that were oldgrowth eucalypt, regrowth eucalypt or understorey trees (%, total n = 901).

	Oldgrowth	Regrowth	Understorey	Total
Coupe				
WR1E	3.8	17.2	79.0	100.0
WR8I	6.2	40.2	53.6	100.0
Both	4.5	23.9	71.6	100.0

Table 6.7b. The percentage of windthrown stems on the aggregate transects that were oldgrowth eucalypt, regrowth eucalypt or understorey trees (%, total n = 901).

	Oldgrowth	Regrowth	Understorey	Total
Coupe				
WR1E	0.0	3.9	96.1	100.0
WR8I	0.0	5.9	94.1	100.0
Both	0.0	4.3	95.7	100.0

Discussion

More than three years after the completion of harvesting and burning in the aggregated retention and stripfell treatments, both the retained aggregates and belts remained predominantly intact. Harvesting damage to edge trees was minimal, although some damage occurred during the subsequent firebreaking operations. Overall, less than 10% of the retained trees across both treatments incurred any damage and only two understorey trees were killed. Less than 10% by area of the retained forest was burnt during the regeneration burning operations. Windthrow of the overstorey eucalypts was not significant. Windthrow of the understorey was significant with approximately one-quarter of the stems blown over. Premature death and/or windthrow, particularly of understorey trees, was exacerbated in burnt areas.

Harvesting and firebreak construction damage

Harvesting in wet eucalypt forests usually involves felling trees away from standing forest and into previously felled areas on a progressive front. The harvesting contractors noted no issues with working around the aggregates, and there was little harvesting damage to trees retained in the aggregates. The biggest difficulty noted was starting the stripfells, as, in this case only, trees had to be felled within undisturbed forest, which is always hazardous (TFITB 2007). Once a gap was created by felling the first one or two trees, the felling proceeded without difficulty. As the edges of the stripfells were established, there were no issues with directionally felling trees away from the edges, and consequently there was little harvesting damage to the retained trees. Most of the damage to the retained trees occurred while preparing firebreaks. Broken bark on the bases of trees standing close to the edge of the harvested area, and root damage to the same trees, were the two major types of damage noted.

In routine partial harvesting operations in Tasmania, where trees are retained on site to grow on for future timber production, minimising damage to the retainers is central to good management, damaged stems being more likely to develop decay (White and Kile 1993). In aggregated retention, where the trees are retained to improve the post-harvest structural and biological diversity of the regenerating stand, damage to the retained trees is less critical, but good forest management practices still require that damage should be minimised.

Burning damage

Across the two treatments, less than 10% of the retained forest was burnt. Given that regeneration burning in variable retention harvesting is always a compromise between the need to remove fuel and create receptive seedbed, and the desire not to incinerate the retained forest, this is an acceptable result (Chuter 2007; Forestry Tasmania 2009). Burning damage to retained forest is not necessarily detrimental, for example there are some beetle species that are drawn preferentially to burnt wood (Schmitz *et al.* 2002; Harrison 2007). However, as the aggregates are also designated as 'lifeboats' for later successional species (Franklin *et al.* 1997), it is important that burning be managed as far as possible to minimise the impact on the aggregates.

Burnt eucalypts, especially where that burning has eroded the base of the tree, have an increased likelihood of subsequent collapse (Whitford and Williams 2001; Neyland 2004; Gibbons *et al.* 2008). Previously fire damaged trees are more likely to be decayed, and fires that establish inside oldgrowth eucalypts can substantially further weaken the stems. Given that it is the oldgrowth eucalypts that are both most likely to provide the sought-after habitat diversity and to contain pre-existing decay columns which renders them susceptible to entry by fire, this also emphasises the importance of minimising the intrusion of the regeneration burn into retained forest.

Stripfell/patchfell –windthrow

The loss to windthrow in the retained belts, by both stem count and basal area, in the first four years after completion of harvesting and burning, was more than double that in the subsequent five years, which indicates that after the initial rapid losses the retained forest has stabilised. This is a similar pattern to that observed in the dispersed retention coupes, where rapid early losses during the first 18 months after regeneration were observed; by age four years few further losses were experienced (Neyland 2004). Forests immediately adjacent to harvested areas in many forest types are most vulnerable to windthrow in the first few years after harvest (Laiho 1987; Harris 1989; Mitchell *et al.* 2001; Moore *et al.* 2003). The regeneration in the harvested strips was moderately well stocked by age six years (Chapter 7) and had reached about 8 m in height (data not shown). This must be beginning to moderate windspeeds in and around the retained belts, and it is anticipated that, as elsewhere, losses to windthrow will further decline over time.

The total loss to windthrow of the understorey of about one-quarter of the stems was substantial. The extent of this loss was exacerbated by the escape from the regeneration burn, as the majority of the burnt stems subsequently died and fell over. The orientation of the strips may also have contributed to the observed windthrow as they were located perpendicular to the prevailing winds, particularly the westerly gales that are typical of spring in Tasmania. A wind-risk model is now available for Tasmania (Wood *et al.* 2008) that identifies the most wind prone parts of the landscape and this should be used when planning future stripfelling operations. Coupe shape and design can also be used to reduce the risk of windthrow (Chen *et al.* 1992; Mitchell 1995; Ruel 1995); avoiding long straight coupe edges, sharp corners, and edges that are perpendicular to prevailing storm force winds are consistent elements in these models.

The biggest impact to the structural integrity of the forest in the belts was the collapse of the fire-damaged oldgrowth eucalypts. They were responsible for the majority of the basal area loss (73%), but also their enormous size meant that their collapse caused a lot of physical damage to the understorey. This physical disturbance then leaves *Nothofagus* more susceptible to myrtle wilt (Kile *et al.* 1989); mature myrtles in particular are susceptible to this disease following disturbances to a stand (Kile *et al.* 1989). Collapsing myrtles some years later can then in turn create more damage. Myrtle was the only species other than the eucalypts to lose more than 10% by stem count and by basal area of the original stocking.

Nine years after the completion of harvesting and burning in the stripfells the section of the retained belt in which the two large oldgrowth eucalypts died is clearly more open that it was pre-disturbance, but the rate of windthrow has slowed considerably and there is some regeneration present. The remaining belt sections and coupe edges are intact and are certainly capable of providing propagules of the desired later successional species into the regenerating forest. Whether or when the retained sections are harvested is a future decision.

Aggregated retention windthrow

During the regeneration burns there were minor incursions by the fire into the aggregates, predominantly on their more exposed north-west sides. The exposure (i.e. the direction that an edge faces) has a strong influence on the microclimate, notably the light and temperature profiles (Wales 1972; Young and Mitchell 1994; Heithecker and Halpern 2007). Regeneration burning is always done in autumn, and the aggregate edges have often been exposed to the sun and wind for much of the summer. Consequently available ground fuels in the north-west side of aggregates are usually drier than fuels in the more sheltered south-east side. If lighting is undertaken when the wind is coming from the west or north-west, as it was in both aggregated retention coupes, then the northwest sides of each aggregate will potentially be vulnerable to the fire.

Conclusions

In the first three years following completion of harvesting and burning operations in the aggregated retention treatments, about a quarter of the standing stems, predominantly small understorey trees and shrubs, have been windthrown. As in the stripfells, the windthrow was worse in areas that had burnt. The windthrow was also worse in smaller aggregates. In variable retention operations in Canada, DeLong (2001) and Burton (2002) found that the size of the aggregates was the single most important factor in determining the amount of wind damage in the forests they studied. In aggregates of less than one hectare windthrow ranged up to 100% of stems whereas in aggregates greater than one hectare windthrow was always less than 25%. The lesson both from this study and such work overseas is that larger aggregates are more stable. They are also easier to maintain intact through the regeneration burn (Chuter 2007). Current recommendations (Forestry Tasmania 2009a) are for aggregates to be between one and three hectares rather than the one-quarter to one hectare aggregates used in this trial.

The majority of the standing forest and the great majority of the eucalypts in the aggregates were still intact and healthy three years after the completion of harvesting and burning. These should continue to provide greater structural and floristic diversity throughout the next rotation, than would be provided by a clearfell burn and sow operation, all else being equal. By the time of the next harvest and assuming that the stand has not been burnt in a stand-replacing wildfire, there will be at least three cohorts of eucalypts, current oldgrowth and regrowth stems, and the new cohort from the current regeneration. This should provide planners of the future with a diverse range of options.

Chapter 7. An examination of stocking and early growth in the Warra silvicultural systems trial confirms the importance of a burnt seedbed for vigorous regeneration in *Eucalyptus obliqua* forest

Introduction

Clearfelling followed by high intensity burning and aerial sowing of seed collected from the harvested area or locally, has been the dominant silvicultural system for tall wet eucalypt forests in south-eastern Australia since the 1960s (Hickey and Wilkinson 1999a). The adoption of this system followed the elucidation of wet eucalypt forest ecology at that time by Gilbert (1959) and Cunningham (1960). In natural conditions eucalypts in wet forests regenerate following infrequent but usually intense wildfires that consume the abundant leaf litter and much of the understorey, thus presenting the shade intolerant eucalypt seedlings with receptive seedbed and high light conditions for early rapid growth (Gilbert 1959; Cunningham 1960a; Ashton 1981b). As practised over the last 40 years, the clearfell, burn and sow (CBS) system has attempted to mirror the natural disturbance regime (Attiwill 1994). Clearfelling in tall wet eucalypt forests is recognised as being relatively safe for the harvesters and productive for the landowner (Mitchell 1993). It is also regarded as relatively benign floristically as all higher plant species present have been shown to regenerate successfully and at least persist following a single disturbance, albeit with different abundances than prior to the disturbance (Hickey 1994; Tabor *et al.* 2007).

Critics of clearfelling have maintained that the natural disturbance regime creates more complex landscape patterns (e.g. Lindenmayer *et al.* 1999) and leaves a greater local structural diversity (e.g. Lindenmayer and McCarthy 2002). Such criticisms of clearfelling have not been unique to Australia, but have had parallels throughout the world wherever temperate forests have traditionally been clearfelled (e.g. Franklin *et al.* 1997). Trials to develop more ecologically-based silviculture for temperate forests, whilst maintaining safe workplaces for the harvesters, have consequently been under development in the last two decades in Australia (Squire 1990; Campbell 1997; Lindenmayer 2007), the Pacific northwest of the USA (Aubry *et al.* 1999; Franklin *et al.* 1999), Canada (Arnott and Beese 1997), South America (Vergara and Schlatter 2006; Heithecker and Halpern 2007; Martinez Pastur *et al.* 2007) and Europe (Fries *et al.* 1997). Trials of alternatives to clearfelling in lowland wet eucalypt forest in Tasmania were undertaken in the 1990s at Forestier (Neyland *et al.* 1999) and Arve (Bassett *et al.* 2000), but neither developed safe and practical alternatives to clearfelling that could be more widely applied. The Forestier trial was compromised by inadequate control of browsing mammals, which left the small gap treatments very understocked. The Arve trial demonstrated that small gaps could be harvested and regenerated, but like the Victorian trial (Squire 1990) found that the overwood significantly suppressed the growth of the regeneration, especially in the small gaps.

The need for research on ‘commercial viability of new and alternative techniques especially for harvesting and regenerating wet eucalypt forests and maximising special species timbers (rainforest species) and rainforest regeneration where appropriate’ was formalised in the Tasmanian Regional Forest Agreement (Commonwealth of Australia and State of Tasmania 1997). Consequently, the Warra silvicultural systems trial (SST) was established to develop alternatives to the traditional clearfell, burn and sow method (Hickey *et al.* 2001). The Warra trial site is dominated by tall *Eucalyptus obliqua* forest (Neyland 2001) the most widespread and abundant commercial native forest type in Tasmania, occupying some 425 700 ha (Public Land Use Commission 1996). These forests at Warra are representative of many of the tall *E. obliqua* forests in Tasmania, particularly of those in southern and south-eastern Tasmania but also, with some qualification, of forests elsewhere in the State (Neyland *et al.* (2000). Hence the findings from this trial can reasonably inform management of tall *E. obliqua* forest elsewhere in Tasmania.

Successfully established and adequate regeneration has long been recognised as part of sustainable forest management (Lutze *et al.* 2004). The Australian Forestry Standard through Criterion 4 ‘Forest management shall maintain the productive capacity of forests’ and more specifically under requirement 4.4.4 ‘The forest manager shall ensure that regeneration of native forests [and establishment of plantations] is effective and timely’, has recognised the central importance of regeneration success (Standards Australia 2003). The quantity and quality of the regeneration in the alternative treatments being examined at the Warra SST, as compared to CBS, is therefore a key measure of their success. The aim of this study was to compare the range of treatments applied within the Warra SST in terms of the density, stocking, and growth of the *E. obliqua* regeneration.

Methods

Study Site

The Warra SST is located within the Warra long term ecological research (LTER) site (latitude: 43° 04' S; longitude: 146° 40' E) which is located between the Weld and Huon Rivers in the Southern forests of Tasmania (Brown *et al.* 2001). The SST occupies south-east facing slopes above the Huon River and ranges in altitude from 50 to 350 m asl. Slopes are gentle to moderate (<20°) and rainfall is about 1450 mm per annum. Soils are variable throughout the SST, but are largely derived from Jurassic dolerite (Laffan 2001). The pre-harvest vegetation within the trial area was multi-aged *E. obliqua* tall wet forest; a number of regrowth-generating fires having burnt through the study area in the last 150-plus years (Hickey *et al.* 1999; Alcorn *et al.* 2001). Stands across the trial site were quite variable in structure as a consequence of the fire history with density ranging from 100 to 300 and in one instance up to 720 eucalypt trees per hectare. Heights ranged between 40 and 65 m and basal area across the trial averaged 80 m^2 ha^{-1}. The understorey vegetation was dense, comprising closed stands of tallow-wood (*Nematolepis squamea*), prickly wattle (*Acacia verticillata*), tea tree (*Leptospermum* spp.) and paperbark (*Melaleuca squarrosa*) over cutting grass (*Gahnia grandis*) and bauera (*Bauera rubioides*) (Neyland 2001). In protected sites where there have been no recent fires the sclerophyllous vegetation is sometimes replaced by callidendrous or thamnic rainforest (*sensu* Jarman *et al.* 1984) understoreys (Neyland 2001).

Harvesting treatments

Seven harvesting treatments were applied across nine coupes or sections. The treatments, their objectives and perceived advantages and disadvantages, and the timing of each operation across the ten years over which the trial was established are detailed in Table 7.1. An aerial view of the trial at the completion of the harvesting and regeneration treatments is shown in Figure 7.1. All the harvesting

Table 7.1. Treatments and objectives[1].

Treatment	**Coupe name**	Harvesting objectives	Potential advantages	**Potential disadvantages**
Clearfell, burn and sow with understorey islands (ground-based harvesting). Clearfell coupes of approximately 20 ha with up to 5% of the coupe to be in dispersed 40 m by 20 m machinery-free areas, high intensity burn, and aerial sowing of on-site or in-zone seed. (CBS-UI).	WR8H WR8B	• Efficient and safe eucalypt harvest with close to maximum potential growth of eucalypt regeneration and enhanced local survival of understorey flora on, and potentially around, the machinery-free areas.	• safe harvesting • low supervision costs • established approach to slash burning • receptive seedbed for eucalypts • low fuel loads post-burn • fast eucalypt growth • high return to grower The understorey islands may also provide: • better survival of late-successional flora, and • a source of propagules to recolonise the coupe.	• high visual impact • few late-successional species • few special species[2] • low structural diversity • smoke • nutrient loss • the understorey islands may present a smoulder risk post burning
Patchfell (cable harvesting) 240 m by 200 m patch, high intensity burn, natural seedfall (PAT).	WR1A (F)	• Efficient and safe eucalypt harvest with maximum potential growth of eucalypt regeneration and adequate biodiversity outcomes. This coupe was harvested to aid investigations into the maximum dispersal distance for eucalypts and special species.	• As above plus this treatment will enable an estimate of the maximum recolonisable strip width applicable in stripfelling.	As above
Stripfell (cable) Openings of c. 250 m by 80 m strips, moderate intensity burn, natural seedfall (STR).	WR1A (N) WR1A (L)	• Harvest the eucalypts as safely as possible, with adequate growth of eucalypt regeneration and enhanced biodiversity outcomes, by retaining strips of unharvested forest between harvested strips of similar size.	• improved special species regeneration • natural seed supply • improved visual impact	• many more coupes required for same area harvested • more roading • more burns • windthrow within retained strips can lead to reduced production
Dispersed retention (ground). 10-15% BA retention, low intensity burn, natural seedfall (DRN).	WR1B WR8C	• Harvest the eucalypts as safely as possible, with adequate growth of eucalypt regeneration and enhanced biodiversity outcomes by retaining individual eucalypts for a full rotation.	• retention of structural diversity • more hollows for fauna • large log habitat • improved aesthetics • natural seed supply	• higher risk to harvesters • difficult fire management • reduced eucalypt seedbed • variable seed supply • potential for reduced eucalypt regeneration growth

Note 1. This table has been developed from Hickey *et al.* (2001) and Hickey *et al.* (2006).
Note 2. Special species are non-eucalypt tree species which can produce fine timber; they include blackwood (*Acacia melanoxylon*), myrtle (*Nothofagus cunninghamii*), celery-top pine (*Phyllocladus aspleniifolius*), sassafras (*Atherosperma moschatum*) and leatherwood (*Eucryphia lucida*).

Table 7.1 (cont). Treatments and objectives[1].

Treatment	**Coupe name**	Harvesting objectives	Potential advantages	**Potential disadvantages**
Aggregated Retention (ground) 30% area retention, majority of harvest within one tree length of retained forest, retain aggregates of 0.5 to 1.0 ha, low intensity burn, natural seedfall (ARN).	WR1E WR8I	• Harvest the eucalypts as safely as possible, with adequate growth of eucalypt regeneration (and special species if present) and enhanced biodiversity outcomes by retaining patches of undisturbed forest for a full rotation.	• retention of structural diversity and habitat • retention of late-successional understoreys • more hollows for fauna • large log habitat • improved aesthetics • lower safety risk than dispersed retention • natural seed supply • special species timber supply	• more coupes and hence more roads and more burns required for the same area harvested compared to clearfelling • difficult fire management
Single-tree/small-group selection (ground) Retain >75% forest cover at all times, permanent primary snig tracks, openings less than one tree height wide, harvest c. 40 m^3 ha^{-1} every 20 years (based on primary production of 2 m^3 ha^{-1} $annum^{-1}$), heaping of slash, mechanical scarification, no burning, natural seedfall (SGS)	WR5D	• Harvest mature trees as safely as possible, with adequate growth of eucalypt and special species regeneration and enhanced biodiversity while maintaining a continuous tall forest cover.	• retention of structural diversity and habitat • improved aesthetics • natural seed supply • greater special species timber supply	• higher safety risk to harvesters • high harvest cost • more coupes and hence more roads required for the same area harvested compared to clearfelling • reduced eucalypt regeneration stocking and growth • damage at subsequent harvests • fire hazard from unburnt slash
Group selection (ground) Retain 70% forest cover, permanent primary snig tracks, harvest 30% of the canopy cover every 30 years, permanent retention of at least 10% of the area, openings twice tree height wide, low intensity burn, natural seedfall.	WR8G	• Harvest mature trees as safely as possible, with adequate growth of eucalypt and special species regeneration and enhanced biodiversity while maintaining a continuous tall forest cover.	• retention of structural diversity and habitat • improved aesthetics • natural seed supply • greater special species timber supply	• more coupes required for same area harvested • more roading • reduced eucalypt regeneration stocking • more burns • damage at subsequent harvests
Control	8J 8K		study long term change	

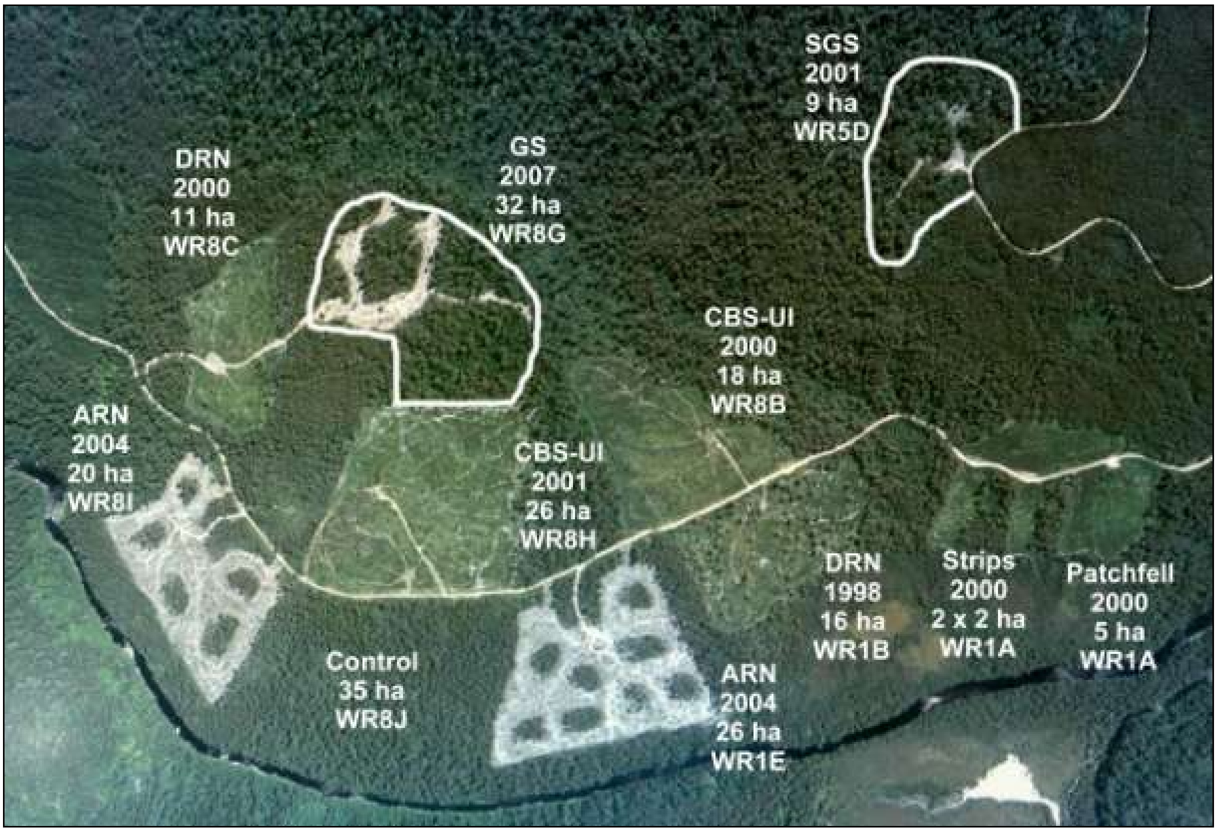


Figure 7.1. Aerial view of the trial as at January 2008.

was undertaken by ground-based machinery, except the patchfell and stripfells which were harvested by cable. The ground-based operations typically comprised an excavator to assist the feller and to prepare the logs for extraction, a skidder to drag the logs to a landing, and another excavator on the landing debarking logs and loading trucks.

In the autumn following harvesting of each treatment, a regeneration burn was applied to remove the harvesting debris and to assist in creating receptive seedbed, except in the first single-tree/small-group selection treatment which was not burnt. A mineral earth firebreak was prepared around the perimeter of the harvested area prior to the regeneration burn to assist in controlling the burn and to provide access for lighting crews. Following the burn the clearfell-with-understorey-islands treatments were aerially sown. The remaining treatments relied on natural seedfall from the retained trees.

The original intention was to have two replicates of each treatment. Whilst this was largely achieved, the duration of the establishment period of the trial (1998 – 2007) meant that there were inevitable variations in the weather patterns from year to year, which particularly affected the slash burning.

Safety issues that arose during the harvesting of the first dispersed retention treatment meant that the guidelines for harvesting the second dispersed retention treatment had to be varied such that there was no requirement for the contractor to retain oldgrowth trees where he felt it was unsafe to do so. As small openings (15 to 45 m across) and no burning in the first single-tree/small-group selection treatment led to unsuccessful regeneration, larger openings of about two tree-lengths wide, and burning, were used in the second replicate of this treatment: single-tree selection was abandoned due to the inherent dangers of this method. Thus the 'replicate' of the single-tree/small-group selection treatment became a group selection treatment. The group selection treatment was completed in 2007, and so is only reported here to age one year.

Regeneration monitoring

Early research in Tasmania showed that achieving successful eucalypt regeneration requires a receptive seedbed, an adequate supply of seed, and monitoring of mammal browsing and control of that browsing if required (Cremer 1960; Cunningham 1960a; Gilbert 1960; Cremer 1969; Cremer 1971). Each of these three parameters (seedbed, seed and browsing) was monitored throughout the course of the trial.

Seedbed

Harvesting native eucalypt forest and subsequent burning of the harvesting debris has significant impacts on the soil (Rab 1996; Bauhus *et al.* 2002; Pennington *et al.* 2004). The harvesting process can cause mechanical disturbance to the soil profile although in most parts of the Warra trial, the primary snig tracks were corded and matted (Wilkinson 2000) to minimise the extent of soil disturbance. The regeneration burn, which is applied to reduce the fuel loads created during the harvesting process and to prepare seedbed that is receptive to eucalypt seed, also has significant impacts on the soil (Raison 1980), especially where the fuels have been heaped up in any way, for example by the clearing of firebreaks around the perimeter of the harvested area, which results in fires of higher intensity and longer residence time (Forestry Tasmania 2004).

In all the burnt coupes, a randomly located grid of sample plots was placed over the coupe within the week following the burn. In all of these coupes except the stripfells, the grid was composed of transects 100 m apart with plots 10 m apart. In the two stripfells (WR1A (N) and WR1A (L)), which were only 80 m wide, a zig-zag system of short transects at 45º to the centreline of the strip was used to increase the number of plots that could be placed within the coupe. Each grid point was permanently marked with a tagged wire peg to assist relocation. The intensity of the burn and the impact of the harvesting disturbance on the soil at each grid point were classified as shown in Table 7.2. The burning and disturbance impacts on the soil are not independent but have a combined effect in terms of the receptivity of the seedbed. Where the soil was burnt to mineral soil (BM) or burnt to ash-bed (B2), it was not considered possible to allocate the point to a disturbance class, partial or complete oxidation having altered the soil beyond the point to which disturbance could be reliably recognised. The combination of burnt-to-litter (BL) and compacted seedbed (D2) was only very rarely observed and there were not sufficient seedlings in this class to allow their use in the subsequent analyses. For each coupe this assessment determined the proportion of the coupe which had burnt, the intensity of the burn (where burnt) and the extent of soil disturbance arising from the harvesting.

Table 7.2. Seedbed burn and disturbance classes.

<u>Burn classes</u>

B0 Unburnt (or burnt so lightly as to not affect the seedbed)
BL Burnt but unburnt litter still present (minor soil heating but soil often not exposed)
BM Burnt to mineral soil (charcoal present over exposed and heated mineral soil)
B2 Ashbed (intense soil heating, soil oxidation)

<u>Disturbance classes</u>

D0 Undisturbed
D1 Revealed (litter removed from mineral soil or soil disturbed and aerated)
D2 Compacted (litter removed and soil compacted, generally from machinery movement)

<u>Seedbed classes</u>

	D0	D1	D2
B0	1	2	3
BL	4	5	n/a
BM		6	
B2		7	

In the unburnt single-tree/small-group selection coupe (WR5D) only, the seedbed within the entire harvested area was surveyed using chain and compass. The coupe was mapped into three seedbed classes: disturbed mineral soil; partially corded tracks and landings with some exposed mineral soil; and deep slash, arising from the piling up of the harvesting debris at the completion of harvesting. Areas of compacted subsoil were rare, and all the exposed soil had been disturbed. As there was no burning, all the exposed seedbed was classified 'unburnt/disturbed' (see Table 7.2).

To compare the nature of the resultant seedbed in each coupe or coupe section, a contingency table was prepared and a chi-square test used to test the independence of the intensity of the planned burn within each coupe against seedbed.

Seedfall

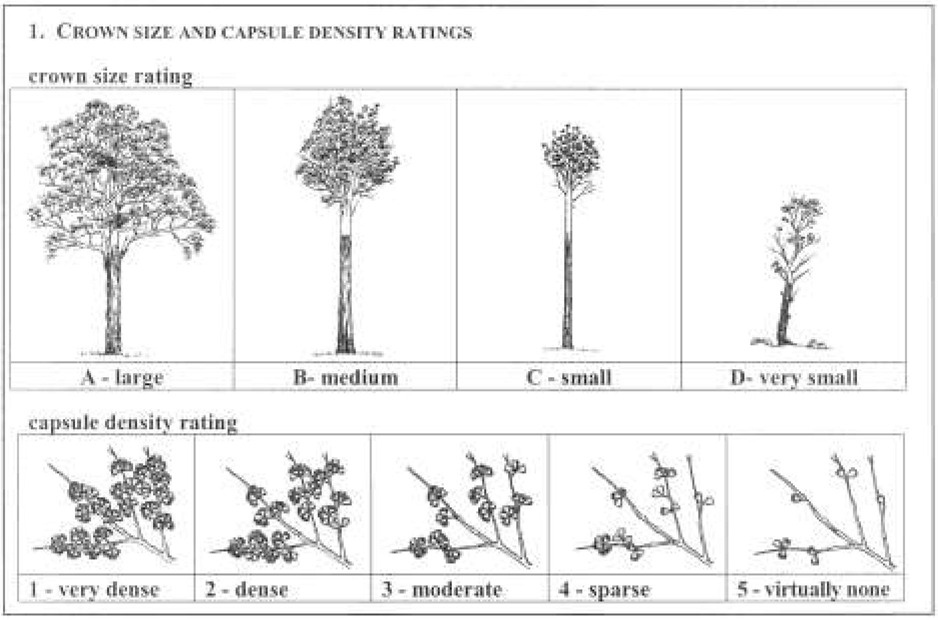
The dispersal characteristics of eucalypt seed are poor, and most seed falls within a distance equivalent to the height of the parent tree (Grose 1957; Cunningham 1960a; Grose 1960; Cremer 1966; Cremer 1977). The trees that are retained in partially harvested coupes were expected to contribute seed within one tree height equivalent radius of the retained tree, but not much further. This limitation is typically built into prescriptions for partial harvests (see for example Forestry Tasmania (2002b)), and was incorporated into the design of the treatments. In the dispersed retention coupes, wherein the average tree height was about 45 m, trees were retained on a spacing of about 30 m. The stripfells and the fairways in the aggregated retention coupes were designed to be no more than two tree heights wide over the majority of the coupe. It was decided quite early in the establishment phase of the experiment to allow natural sowing of the coupes wherever possible; they could have been oversown with locally collected seed, and this would probably have increased the amount of seedling regeneration, but would also have made it more difficult to subsequently assess the potential of the different treatments to regenerate naturally.

The clearfell coupes were aerially sown with a known rate of seed. In order to assess the likely seedfall in the non-clearfell coupes, two approaches were used; visual assessment of the seed crop in retained trees (both within and adjacent to coupes) and seed traps.

Visual assessment methods can provide an indication of the relative size of a potential seed crop – the arrangement of the capsules behind the leaves in *Eucalyptus* means that the abundance of the capsules can be readily judged (Forestry Tasmania 2007a). However this provides no information as to the viability of that seed or the proportion of seed to chaff; seed is released from the capsules before the capsules themselves are abscised from the tree. Neither is it ultimately possible to assess the actual seedling per cent (measured as the number of seedlings that arose from each one hundred seeds sown). A range of factors will influence seedling per cent e.g. the receptivity of the seedbed (how much exposed mineral soil, how much deep litter, etc), the weather following the sowing or initiation of natural seedfall and/or the extent of mammal browsing. Fagg (1981) reported that seedling per cents from 2 to 5 are considered typical in high elevation mixed species forests in Victoria; sowing rates in Tasmania are based on an expected seedling per cent of about 4 (Forestry Tasmania 2007a).

Visual assessment

The visual assessment system used is illustrated in Figure 7.2 (Forestry Tasmania 2007a) except that rather than calculating point scores for a location the seed crop was assessed in every tree that could potentially contribute seed to the coupe. In the two aggregated retention coupes (WR8I and WR1E), the seed crop was assessed in all the trees (both within retained aggregates and around the perimeter of the coupe) whose crowns had an angle greater than 45º from any harvested part of the coupe. In the patchfell (WR1A (F)) the seed crop was assessed in all the trees around the perimeter of the coupe whose crowns had an angle greater than 30º from any harvested part of the coupe. The lower angle was used in order to increase the sample size. In the two dispersed retention coupes (WR1B and WR8C), the seed crop was assessed in all the retained trees within the harvested area. Trees retained in the adjacent unharvested forest were not assessed though it became clear by age three years that these trees had in some places contributed generous amounts of seed that had become established seedlings. It was assumed that they had similar seed crops to trees inside these coupes.



2. SEED CROP POINTS SCORES

At each point, do a 360° sweep recording the tree species, crown size and capsule density rating, and the angle of elevation to the top of the crown.
Calculate the point score for each species at each point from the table below.

Angle to top of crown		*crown size rating*			
'High' crowns (> 45°)		A or B	C		D
'Low' crowns (>30° <45°)				A or B	C
	1	60	30	20	10
capsule	2	40	20	13	7
density	3	20	10	7	3
rating	4	8	4	3	1
	5	4	2	1	1

Figure 7.2. Seedcrop assessment protocol.

Seedtraps

Fifteen to twenty circular 1 m^2 and 1 m high seedtraps were placed into all coupes except the two CBS coupes (WR8B and WR8H) and the patchfell (WR1A (F)) shortly after completion of the burn, or in the case of the unburnt WR5D shortly after the completion of harvesting. The number and arrangement of the traps in each coupe varied in response to the differing layout of each coupe. Where a significant delay was expected between the completion of harvesting and the regeneration burn, the traps were placed following the completion of harvesting, then removed for the burn, then replaced. The seedtraps were maintained in each coupe for at least two years. In all the coupes except the two clearfells, which had high intensity burns, the regeneration burn was of moderate intensity and patchy, so some seed on the ground and some established seedlings could reasonably be expected to have survived the burn. There may not have been sufficient traps randomly located across every coupe within the trial to enable a statistically valid estimation of the seedfall. However, the combination of the visual seedcrop assessment and the seed trap results was considered to provide a useful indication of the seedfall on each coupe.

The contents of each trap were collected quarterly (WR1B, WR1A (N and L) and WR8C) or monthly (WR5D, WR8I, WR1E and WR8G), brought back to the laboratory and sorted. Seed that was retained in capsules was ignored. The cleaned seed was stratified for a week at 0ºC and then placed in a constant temperature chamber at 20ºC for three weeks and germinants counted. Since some seed may have germinated in the traps and died through drought or waterlogging in the period between collections the reported seedfall may be an underestimate.

The two clearfell burn and sow coupes (WR8B and WR8H) were aerially sown with a mixture of on-site and in-zone seed. On-site seed is that collected from the same coupe during harvesting, and in-zone seed is that collected within a similar biogeographic zone (Forestry Tasmania 2007a). The seed was sown onto freshly burnt seedbed six days (WR8B) and nine days (WR8H) after burning (Forestry Tasmania 2002a).

Browsing

Browsing of eucalypt seedlings by native mammals can cause significant damage to individual seedlings and reductions to stocking and growth, especially in the first two years after germination (Cremer 1969; Wilkinson and Neilsen 1995; Forestry Tasmania 1999). To monitor browsing, a transect of 50 seedlings was established in each coupe in the summer after the regeneration burn following prescribed procedures (Forestry Tasmania 1999). In the case of WR5D, the unburned single-tree small group selection coupe this was done after the completion of harvesting. The transect generally followed an irregular line from the landing to the edge of the coupe. In some instances and in order to increase the area sampled, the monitoring was established as two transects of 25 seedlings each. Seedlings were selected at approximately 2 m intervals. The height of each seedling was measured monthly and any browsing damage noted.

If the average height of the seedlings over successive measurements was steady or decreasing, and more than half of the monitored seedlings were browsed, then browsing control was initiated. The actual impact of the browsing on seedling density was not recorded.

Regeneration

Seedling regeneration was assessed in March each year for three years after the regeneration burn, using the quadrat-count method (Lutze *et al.* 2004). The stocked-quadrat method has been shown to provide good information about the minimum likely abundance and distribution of the regeneration (Dignan and Fagg 1997; Forestry Tasmania 2003; Lutze *et al.* 2004). By also counting the number of seedlings on each plot (the quadrat-count method), seedling density (stems ha^{-1}) can also be estimated (Lutze *et al.* 2004).

A randomly located grid was placed over the coupe with lines either 50 m or 100 m apart; the closer spacing of the lines enables sufficient plots to be located within smaller coupes. Dignan and Fagg (1997) show that by increasing the number of plots surveyed, the lower confidence limit of the result also increases. For example, the lower confidence limit for a survey of 30 plots returning 65% stocked plots is 48%, whereas that for a survey of 50 plots is 52%. The relative gains in accuracy reduce as the number of plots increases. In this experiment, the sampling target was set at 100 plots in coupes > 10 ha, and at least 30 plots in smaller coupes or coupe sections.

Plots were located every 20 m along the lines. A circular 16 m^2 plot centred on the sample point was searched for acceptable eucalypt seedlings. Acceptable seedlings (hereafter referred to as seedlings) have at least three leaf pairs, and are healthy with green, not purple leaves and have minimal insect or mammal browsing damage (Forestry Tasmania 2003). The number of seedlings on the plot was counted. The height of the tallest seedling on the plot was recorded, as was the mean height and dominant species of the competing understorey vegetation. The nature of the seedbed (Table 7.2) in which the tallest seedling was growing was recorded.

For each coupe the percentage of stocked plots was calculated. The accepted standard for even-aged regeneration in wet eucalypt forest in both Victoria and Tasmania is that at least 65% of the assessed plots are stocked (Dignan and Fagg 1997; Forestry Tasmania 2003). Seedling density (stems ha^{-1}) was estimated by taking the average of the number of seedlings recorded in each plot and multiplying by 625 (10 000/16 m^2). The mean height of the tallest seedlings, and of the understorey, was calculated. The dominant understorey species for each coupe was the species that dominated the greatest number of plots. To compare the density of the seedlings in each 16 m^2 plot, a contingency table was prepared and a chi-square test used to test the independence of seedling density against seedbed.

Seedling growth

A set of single-tree plots was established in each coupe to assess the influence of the seedbed, the competing vegetation and the adjacent unharvested forest on seedling growth. The plots were established in the second winter following burning when the seedlings were about one-year old, from the same grid as used for the seedbed assessment. The plots were remeasured at age three years.

The nearest dominant seedling to each seedbed assessment point was identified, tagged with a numbered aluminium tag, and measured. Dominant seedlings were defined as seedlings that were healthy and at least as tall, and preferably taller, than the surrounding vegetation. As the plots were 10 m apart, the ‘nearest’ seedling was limited to a distance of 5 m. If no dominant seedling could be located within 5 m, nothing was recorded for that plot. The bearing and distance of the seedling from the plot point was recorded.

The height (cm), the diameter (mm) of the root collar immediately above any basal swelling, the diameter (mm) of the stem either at one third of the height of the tree or 1.3 m, whichever was the least, and the spread of the crown (cm) in both the north-south and east-west direction of each tree were measured. These measurements are hereafter referred to as seedling variables. The nature of the seedbed in which the seedling was growing was recorded (Table 7.2).

The cover-abundance of the surrounding vegetation on a plot of 16 m^2 centred on the seedling was recorded using a modified Braun-Blanquet scale (1 = <1% cover, 2 = 2 to 5% , 3 = 6 to 25%, 4 = 26 to 50%, 5 = 51 to 75%, 6 = 76 to 100%) (Mueller-Dombois and Ellenberg 1974) for each vegetation guild. The mean height (cm) of each guild (trees, shrubs, ferns, sedges and herbs) was measured. Grasses were originally included in the assessment but as their cover and abundance was so uniformly low this was abandoned. Only eucalypts were defined as trees. The shrub layer includes tall shrubs such as dogwood, (*Pomaderris apetala*), tea tree (*Leptospermum* spp.), lancewood (*Nematolepis squamea*), paperbark (*Melaleuca squarrosa*) but also low shrubs such as *Bauera rubioides*. The dominant species in the plot was noted. Measurements pertaining to the vegetation are hereafter referred to as vegetation variables.

The basal area of the retained trees, and the trees in the adjacent unharvested forest around each seedling, were assessed at age 1 year using a prismatic wedge with a basal area factor of 2.

Preliminary analysis of the distribution of the single-tree plot data across seedbed classes revealed that the data was unbalanced in most coupes, with some seedbed classes over- and some under-represented. To balance the data, additional transects were established as required, parallel to and off-set from the original transects, and a transect was set out on the perimeter of most coupes to deliberately sample additional plots in the windrow on B2 (oxidised soil) seedbed and along the firebreak on B0/D2 (unburnt/compacted) seedbed. In these cases, a seedling was selected where the nearest dominant seedling within 5 m was on B2 or B0/D2 seedbed, or rejected if it was on any other seedbed class, every 50 m along the transect. The additional transect started from the same randomly located point as used to establish the original grid and was located within a month of the original transect being established. Seedling growth in winter is very slow and any growth between the two measurements was considered minimal.

Preliminary analyses of the single-tree plot data were conducted using Statgraphics Plus 2.1 (Statistical Graphics Corporation 1994-1996). A Pearsons product moment correlation matrix was prepared to examine the relationships between the stem variables, seedbed, the vegetation variables and the retained basal area.

The distributions of height within classes were found to be highly skewed. Transformation of the height data to logarithmic scale to overcome variance inequality and non-normality was not an option because increasing means were not associated with increasing variances. However, the Central Limit Theorem establishes that for the large samples that are present in the data it is reasonable to assume that the distribution of the class means is approximately normally distributed (McPherson 2001). To allow for coupe-to-coupe variability, variance estimates were obtained from the within-coupe data and a weighted average computed for the variance across coupes for each class with the weighting based on within-coupe sample size. Pairwise comparisons were then made among classes using z-tests allowing for differences in variances among classes. Because there are multiple pairwise tests being undertaken a p-value of less than 0.01 was used as an indicator of significant difference.

Results

Seedbed

High intensity burns were achieved in the clearfell with understorey islands (WR8H and WR8B), the patchfell (WR1A (F)) and the two stripfell (WR1A (N) and (L)) treatments. The low intensity burn intended for the second dispersed retention coupe (WR8C) was much hotter than intended, resulting in the death of many of the retained trees (Neyland 2004). The intended low intensity burns were achieved in the first dispersed retention coupe (WR1B), the two aggregated retention coupes (WR8I and WR1E), and the group selection coupe (WR8G). The single-tree/small-group selection coupe (WR5D) was unburnt.

There was a very clear relationship between the intensity of the burn and the abundance of burnt seedbed (chi-square 310.37, Df = 48, $p = 0.0000$; Table 7.3); the hotter the fire, the more burnt ground.

The dispersed retention coupe (WR1B), lit under the most conservative weather conditions, had only about one quarter of the coupe burnt. The group selection coupe (WR8G) had the harvesting debris rough-heaped leaving about one third of the coupe as disturbed mineral soil, about one third undisturbed and one third burnt. The patchfell and stripfells (WR1A) were burnt under warmer and drier conditions but the heavily-shaded western sides of the strips remained largely unburnt. The aggregated retention coupes (WR81 and WR1E) were prepared with a clear intention not to burn the aggregates and the fires were lit under conservative weather conditions; the nature of the seedbed reflects the low intensity burn that resulted. In the single tree/small group selection coupe (WR5D) approximately one third of the coupe was covered by two-to-three metre deep harvesting slash, piled up at the completion of harvesting, with about one third of the coupe being disturbed mineral soil and about one third being undisturbed. In the two clearfell with understorey island coupes (WR8H and WR8B) which were burnt under routine high intensity burning conditions, almost 90% of the seedbed was burnt ground.

Table 7.3. Seedbed assessment. Percentage of each coupe in each seedbed class. n = the number of seedbed assessment plots established in each coupe.

	Seedbed Class	B0D0	B0D1	B0D2	BLD0	BLD1	BM	B2	n	% burnt[1]
		1	2	3	4	5	6	7		
Coupe	Treatment									
WR8H	CBS – UI	1	9	4	24	23	30	11	255	88
WR8B	CBS – UI	3	9	2	20	9	32	26	146	87
WR1A (F)	PAT	1	6	8	25	6	36	18	113	85
WR1A (N)	STR	6	38	2	34	10	8	2	50	54
WR1A (L)	STR	3	34	12	22	3	22	4	68	51
WR1B	DRN	51	17	5	7	6	11	3	146	27
WR8C	DRN	4	11	2	22	16	31	14	139	83
WR1E	ARN	30	12	3	29	5	19	3	112	56
WR8I	ARN	32	24	1	13	8	17	6	104	44
WR5D	SGS	24	36	3	n/a	n/a	n/a	n/a	148	0
WR8G	GS	33	27	4	12	0	9	15	158	36

Note 1. Burnt seedbed is the sum of classes 4, 5, 6 and 7.

Seedfall

Seedfall varied considerably across the trial (Tables 7.4 and 7.5). In WR1B, WR8I, and WR5D, the seedfall was in the order of hundreds of thousands of eucalypt seeds per hectare. Reasonable amounts of seed fell or were sown onto the remaining coupes, with the exception of WR8C. In WR8C light seedcrops were present in some of the scattered oldgrowth trees remaining on the coupe at the completion of harvesting, but there was very little seed in the crowns of the regrowth trees. Just 13 seeds were caught in 18 traps over the two years following the regeneration burn.

Table 7.4. Summary of eucalypt seedfall data.

Coupe	Treatment	Total number of viable seeds collected	Sowing rate or equivalent (viable seeds per hectare)	Relative seedfall
WR8H	CBS – UI	n/a	47 000	Moderate
WR8B	CBS – UI	n/a	44 000	Moderate
WR1A (F)	PAT	n/a	33 000[1]	Moderate
WR1A (N)	STR	32	36 000	Moderate
WR1A (L)	STR	27	30 000	Moderate
WR1B	DRN	1368	720 000	Very heavy
WR8C	DRN	13	7 000	Light
WR1E	ARN	139	70 000	Moderate
WR8I	ARN	534	270 000	Heavy
WR5D	SGS	191	320 000	Heavy

Note 1. The sowing rate for WR1A (F) is estimated from the average of that for the two strips as traps were not located in WR1A (F).

Table 7.5. Seedcrop scores.

Treatment	Dispersed retention		Aggregated retention		Patchfell
Coupe	WR8C	WR1B	WR1E	WR8I	WR1A (F)
No. of trees assessed	85	145	452	315	136
Mean score (points)	5.6	7.5	8.7	5.9	5.9

(Refer to Figure 7.2 for ratings)

The seedcrop scores in the dispersed and aggregated retention coupes show little relationship with the seedfall as assessed in the traps. The seedcrop scores in all five coupes were similar; ratings per tree ranged between 0 and 20 points (see Figure 7.2), and the mean coupe scores ranged from 5.6 to 8.7 points, which indicates light to moderate seed crops. Yet almost no seed was trapped in WR8C compared to large amounts in WR1B. This reflects the difficulties in accurately assessing seedcrops as discussed above.

Browsing control

In August 1999 (WR1B), May 2001 (WR8C), and May 2005 (WR8I and WR1E), the browsing transect indicated that seedlings were being very heavily browsed. For all coupes, poisoning with 1080 (sodium monofluoroacetate) was undertaken to reduce the number of browsing animals. In December 2005 the use of 1080 poison on State forest was discontinued. Thereafter, if seedlings were being browsed beyond acceptable levels, professional shooters were engaged, and small numbers of animals were shot.

Regeneration stocking and density

By age three years, all coupes had reached or were close to the standard of 65% of 16 m^2 plots being stocked with seedlings, except for WR5D (37%) (Table 7.6, Figure 7.3). There was significant ongoing recruitment over time. All the dispersed and aggregated retention coupes were well short of the target stocking at age one year, but by age three years were at or close to the target stocking. The stripfells reached the target at age one year but continued to stock up over the next two years.

The seedling density at age three years was quite low in many of the coupes (Table 7.6, Figure 7.4); the patchfell (WR1A (F)), the second dispersed retention coupe (WR8C), both aggregated retention coupes (WR8I and WR1E) and the single-tree/small group selection coupe (WR5D) were all well below the commercially desirable minimum seedling density of about 2500 stems ha^{-1} (Forestry Tasmania 2003). The first dispersed retention coupe (WR1B) achieved this density at age 3 years as did the stripfells and patchfells (WR1A). The two CBS-with-understorey-islands coupes (WR8H and

Table 7.6. Regeneration survey summary for all coupes at years one, two and three following regeneration treatment.

Coupe	Treatment	Number of plots	Stocking (%)	Density (stems ha^{-1})	Eucalypt height (cm)	Dominant scrub spp.	Scrub height (cm)
Year one							
WR8H	CBS – UI	131	94	7580	41	P. apet	28
WR8B	CBS – UI	87	82	3180	27	G. gran, P. apet[1]	25[2]
WR1A (F)	PAT	55	60	1875	21	P. apet	27
WR1A (N)	STR	41	79	2140	25	A. mucr	25
WR1A (L)	STR	38	63	1680	21	A. vert	36
WR1B	DRN	115	50	1060	17	G. teuc	38
WR8C	DRN	50	38	400	16	G. teuc	29
WR1E	ARN	128	34	530	18	G. teuc	29
WR8I	ARN	106	42	740	27	G. teuc	25
WR5D	SGS	150	27	530	4	G. gran	10
WR8G	GS	158	28	420	22	G. gran	10
Year two							
WR8H	CBS – UI	136	95	9060	138	P. apet	79
WR8B	CBS – UI	91	88	4580	108	G. gran, P. apet	80
WR1A (F)	PAT	48	69	2214	92	P. apet	88
WR1A (N)	STR	56	84	2880	109	G. gran, S. mini	103
WR1A (L)	STR	47	81	2540	71	S. mini	103
WR1B	DRN	142	77	2100	52	G. teuc	38
WR8C	DRN	76	58	1250	50	G. teuc	64
WR1E	ARN	120	52	1240	31	G. teuc	56
WR8I	ARN	89	73	1460	42	G. gran	62
WR5D	SGS	143	31	390	15	G. gran	56
Year three							
WR8H	CBS – UI	116	92	9960	192	P apet	109
WR8B	CBS – UI	97	93	4410	205	G. gran	113
WR1A (F)	PAT	66	59	1761	217	G. gran	126
WR1A (N)	STR	55	95	3770	230	G. gran	94
WR1A (L)	STR	61	80	2700	216	G. gran	88
WR1B	DRN	76	83	2960	104	G. teuc*	42
WR8C	DRN	89	63	1200	112	G. gran	105
WR1E	ARN	125	63	1260	104	G. gran	81
WR8I	ARN	82	66	1720	141	G. gran	86
WR5D	SGS	112	37	826	45	H. inci*	25

Note 1. Species codes; A. mucr, *Acacia mucronata*, A. vert, *Acacia verticillata*, G. gran, *Gahnia grandis*, G. teuc, *Gonocarpus teucrioides*, H. inci, *Histiopteris incisa*, P. apet, *Pomaderris apetala*, S. mini, *Senecio minimus*.
Note 2. The dominant species and/or the height thereof at these times was determined from the single-tree-plot data as this data was not recorded during the regeneration surveys.

16 m² stocking at ages 1, 2 and 3 years for all coupes at the Warra SST

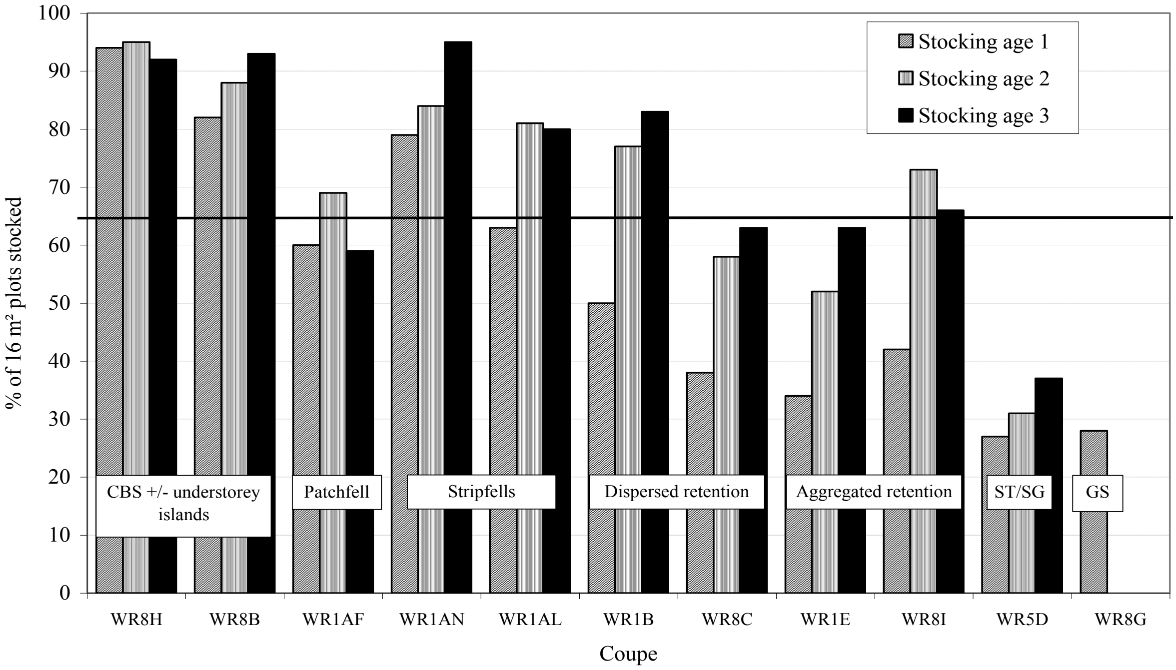


Figure 7.3. 16 m^2 stocking at ages 1, 2 and 3 years old for all coupes at the Warra SST.

Seedling density at ages 1, 2 and 3 years for all coupes at the Warra SST

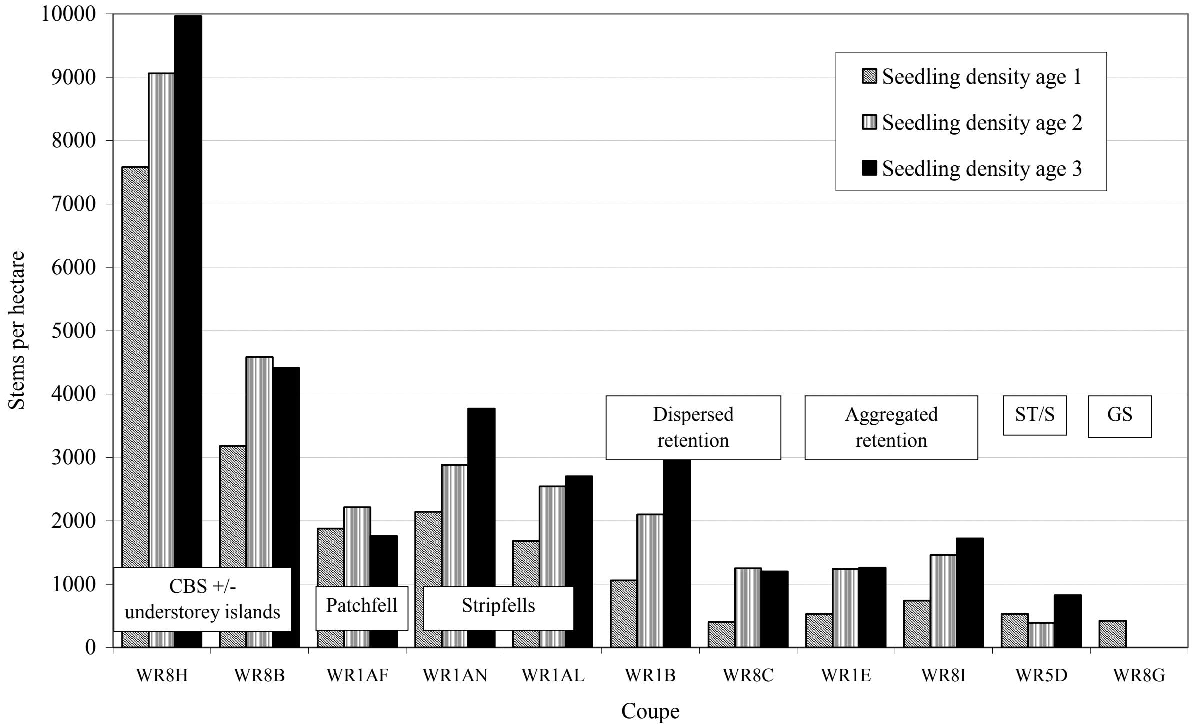


Figure 7.4. Seedling density at ages 1, 2 and 3 years old for all coupes at the Warra SST.

WR8B) reached the desirable seedling density at age one year, but with a considerably higher density in WR8H. Part of the difference in the seedling density between WR8H and WR8B may be due to a waterlogging and freezing event that was observed in WR8B in the second winter after the burn that was associated with high seedling mortality. In WR8H the seedling per cent was about 20; 47 000 seeds ha^{-1} were sown and there were 10 000 seedlings ha^{-1} by age 3 years.

There was a very clear relationship between the intensity of the burn and the density of seedlings in the 16 m^2 regeneration survey plots (chi-square 143.77, Df = 12, p = 0.0000; Table 7.7). Seedling density was significantly lower than expected by chance alone on unburnt and undisturbed seedbed, and significantly higher than expected on burnt-to-mineral-soil and ashbed seedbed.

Table 7.7. Chi-square analysis of seedling density class against seedbed class.

	Observed				Expected				Contribution to chi-square				
Seedling density class	1	2	3	Sum	1	2	3	Sum	1	2	3	Sum	%
Seedbed class													
1	101	25	1	127	55.5	48.5	23.0	127	37.2	11.4	21.0	69.6	48.4
2	78	80	22	180	78.7	68.7	32.6	180	0.0	1.8	3.4	5.3	3.7
3	36	13	12	61	26.7	23.3	11.0	61	3.3	4.5	0.1	7.9	5.5
4	45	34	10	89	38.9	34.0	16.1	89	0.9	0.0	2.3	3.3	2.3
5	22	23	14	59	25.8	22.5	10.7	59	0.6	0.0	1.0	1.6	1.1
6	60	103	50	213	93.2	81.3	38.5	213	11.8	5.8	3.4	21.0	14.6
7	28	45	44	117	51.2	44.7	21.2	117	10.5	0.0	24.6	35.1	24.4
Total	370	323	153	846	370	323	153	846				143.8	

Notes. Seedling density classes – 1 = No seedling, 2 = 1 to 5 seedlings, 3 = 6 or more seedlings
Seedbed classes as Table 7.2.

Correlations

Seedling variables were all strongly correlated (Table 7.8). In subsequent analyses, seedling height was used as the dependent variable. There was a moderately strong correlation between seedling height and the height of competing seedlings on the same plot. In the different guilds of plants in the understorey, height and cover of the shrubs (0.4268), sedges (0.6981), ferns (0.8523) and herbs (0.6661) were also strongly correlated in most cases. The denser the cover the taller the understorey species tended to be. There was not a strong correlation between the seedling height and the basal area of the surrounding retained trees, indicating that at this early stage of the stand development, the retained trees were having little influence on growth.

Table 7.8. Pearson's product moment correlation analysis. Only strong and significant correlations are shown.

	Height	RCD	DBH	NS	EW
Seedling height	-				
Root collar diameter	0.9323	-			
Diameter at breast height	0.9413	0.9695	-		
Crown width north-south	0.9176	0.9175	0.9175	-	
Crown width east-west	0.9009	0.9138	0.9114	0.9305	-
Height of competing seedlings	0.6816	0.6079	0.6027	0.5829	0.5735

Note. Strong and moderately strong correlations not shown above: Shrub height and shrub cover 0.4268, Sedge height and sedge cover 0.6981, Fern height and fern cover 0.8532, herb height and herb cover 0.6661, tree height and tree cover 0.6619.
Note. For all correlations shown, n = 871 and p = 0.0000

Seedling growth

The analysis of the single-tree plot height data (Table 7.9, Figure 7.5) shows that seedlings growing on ashbed (seedbed class 7) are growing significantly faster, on average, than seedlings growing on any of the other seedbed types. Seedlings on burnt-to-mineral soil (class 6) are growing significantly faster, on average, than seedlings growing on any of the other seedbed types except ashbed (class 7). Seedlings on burnt-to-litter-and-disturbed seedbed (class 5) are growing significantly faster, on average, than seedlings growing on unburnt-and-undisturbed seedbed (class 1), unburnt-and-disturbed seedbed (class 2) or unburnt-and-compacted seedbed (class 3) but are growing at similar rates to seedlings on burnt-and-undisturbed seedbed (class 4). Seedlings on seedbed classes 1, 2 and 4 are growing at similar rates. Seedlings on compacted soil (class 3) are growing significantly slower than seedlings growing on any other seedbed class.

Table 9. Significance values for pairwise comparisons of differences between seedling heights by seedbed classes (as defined in Table 3).

Seedbed class	1	2	3	4	5	6	7
1		0.443^{ns}	0.000	0.643^{ns}	0.007^{ns}	0.000	0.000
2	0.443^{ns}		0.000	0.127^{ns}	0.000	0.000	0.000
3	0.000	0.000		0.000	0.000	0.000	0.000
4	0.643^{ns}	0.127^{ns}	0.000		0.013^{ns}	0.000	0.000
5	0.007^{ns}	0.000	0.000	0.013^{ns}		0.000	0.000
6	0.000	0.000	0.000	0.000	0.000		0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	

Note. p-values are computed assuming z-values are approximately Normally distributed which is justified by the large number of observations per class. Any p-value less than 0.01 provides evidence that the corresponding pair of classes is likely to have a different mean.

ns – not significant

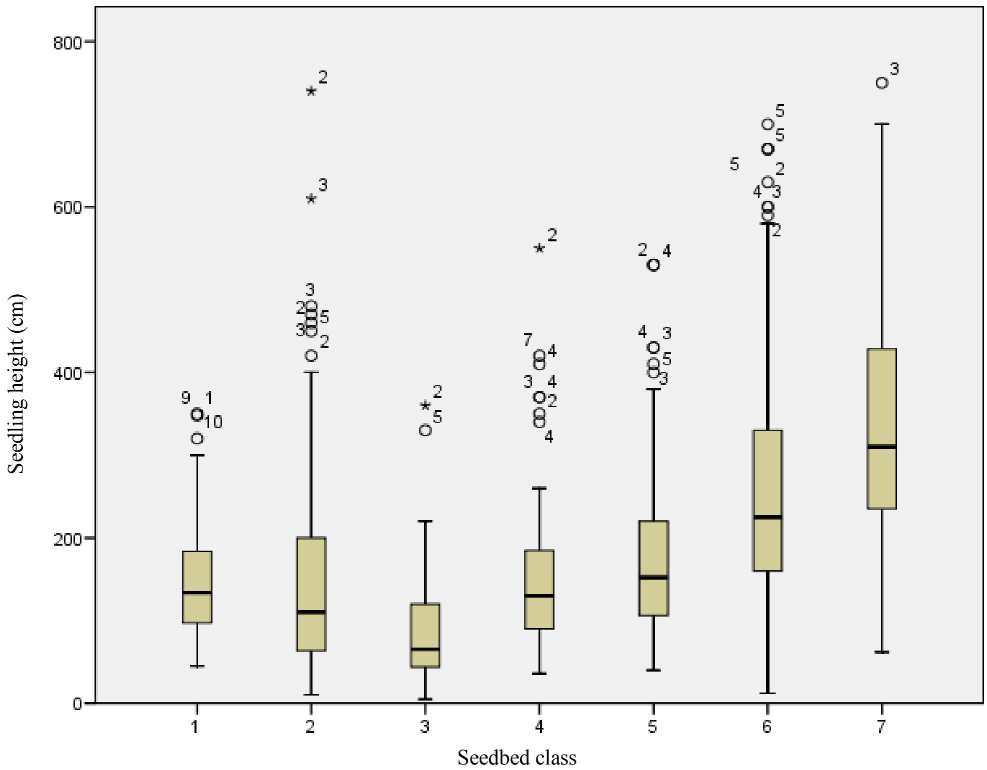


Figure 7.5. Seedling heights by seedbed class. The seedbed classes are as in Table 7.2 and page 169 and 170. The numbers above each box and whisker indicate coupe: 1 = WR1B, 2 = WR1A L, 3 = WR1A N, 4 = WR1A F, 5 = WR8B, 6 = WR8C, 7 = WR8H, 8 = WR5D, 9 = WR1E, 10 = WR8I.

Discussion

Seedling establishment

Numerous factors influence seedling germination and establishment. The rate of sowing or natural seedfall, water and light availability, soil temperature, frost, waterlogging, seedbed receptivity, seed predation, browsing by mammals particularly at the cotyledon stage and overstorey density have all been reported to affect germination and establishment in ash group eucalypts (Ashton 1979; Battaglia and Reid 1993; Cunningham 1960b; Forestry Tasmania 1999; Stoneman and Dell 1994; Van der Meer *et al.* 1999). To meet the aims of this study, as far as possible these factors were held steady or measured. Rainfall in the Warra region is high and drought stress is rarely an issue. Browsing of seedlings was monitored and when it reached unacceptable levels it was controlled, but not eliminated. Since browsing intensity varied across the trial and between treatments, this factor may be responsible for some of the unexplained variation in stocking rates and seedling growth. Seedfall rates were known or estimated, seedbed receptivity was measured and the basal area of retained and adjacent trees was measured.

The highest seedling densities in this trial were in those coupes that received a high intensity burn and that were aerially sown immediately following the burn. Acceptable seedling densities also developed in those coupes receiving a high intensity burn and where the amount of natural seedfall following the burn was at similar levels to that in the aerially sown coupes. Seedlings establish most readily on well burnt seedbed, and least readily on unburnt and undisturbed seedbed. All else being equal, the greater the proportion of burnt seedbed within the coupe, the higher the seedling density is likely to be. Of the coupes burnt at lower intensities, only WR1B, which had a very poor burn but a very high rate of natural seedfall, achieved a commercially acceptable seedling density. Where adequate natural seedfall cannot be assured, artificial oversowing, as has been done successfully on clearfelled wet eucalypt forest coupes for many years (Forestry Tasmania 2008), can be undertaken to improve seedling density.

The ongoing recruitment of seedlings observed in many of the treatments from age one year to age three years demonstrates the value of retained trees for regeneration (Florence 1996). Ongoing seedfall enabled many of the treatments to reach desirable stocking levels by age three-years that had not been achieved by age one-year. The ongoing recruitment also refuted conventional wisdom that the seedbed remains receptive for only about one year following the regeneration burn.

Seedling growth

The nature of the seedbed in which the seedling has established was the single biggest factor in the early height growth rates of the young seedlings. The impact of burning on seedling growth, the 'ashbed' effect, is well established for many eucalypts (Pryor 1960; Chambers and Attiwill 1994). This study shows that not only burning but the intensity of that burning is important, as seedling height growth rates were strongly related to that intensity. Seedlings that had established in hotly burnt seedbeds were growing faster than those in lightly burnt seedbeds, which in turn were growing faster than those in unburnt seedbeds. Seedlings in compacted seedbeds from which the topsoil had been removed grew very slowly and were often overtopped by competing scrub; many of these seedlings were impossible to find by age three years and had presumably died. Rab (1994) has shown that increasing soil bulk density is linearly related to decreasing height and diameter growth in *E. regnans* seedlings in Victoria, and it is likely that a similar effect is at work here. The large variation in seedling growth both within coupe and by seedbed type suggests that factors other than the nature of the seedbed contribute to the final outcome. Natural eucalypt regeneration in wet forests tends to be prolific and there is then intensive selection within the stand for final dominants (Jacobs 1955; Griffin and Cotterill 1988). The dominants in these stands began to emerge as early as age 3 years.

Van der Meer (1999) observed seedling growth in *E. regnans* on burnt seedbeds to also be greater than that on unburnt seedbeds at age three years, but found that by age eight years the effect was no longer significant (Van der Meer and Dignan 2007). In contrast, Lockett (1998) has shown that the influence of burnt seedbeds on the growth of the regeneration dominated by *E. obliqua* may persist for 10 to 15 years. Bauhus *et al.* (2002) found height and diameter growth of *E. regnans* at age nine years to be increased significantly in response to fire intensity. Monitoring of this trial is planned to continue for at least 10 years, to further examine these trends at Warra.

The only coupe within the trial in which light was limiting to the growth of the regeneration was the single-tree/small-group selection coupe, WR5D. Alcorn (2002) showed that in gaps of less than 30 m diameter, light levels would be less than the approximately 27% of full incident light that is required for initial seedling establishment. Most of the harvested area of WR5D was in openings less than 30 m wide and this is reflected in the low final stocking and seedling growth rates in this treatment.

This study has confirmed the importance, and practical necessity, of burning to create seedbed, to promote abundant regeneration and to foster rapid early growth of eucalypts. Rapid early growth is important for seedlings to gain dominance over dense competing vegetation. At Warra, height growth of seedlings on burnt seedbed was approximately twice that on unburnt seedbed over the first three years. Sufficient seedbed was created in both aggregated and dispersed forms of variable retention to allow regeneration to meet stocking standards by year three, but usually not at year one. This provides some support to the prediction that variable retention, particularly aggregated retention, could be a practical silvicultural alternative to clearfelling in tall eucalypt forests although regeneration may be less reliable. If aggregated retention is to be successfully applied, as measured by the seedling density and height growth of the regeneration, finding ways of successfully and consistently burning such coupes post-harvesting will be essential.

Chapter 8. Alternative silvicultural systems for wet eucalypt forests; can these underpin a social licence to operate?

The social and political framework

Clearfelling of wet eucalypt forests commenced in Tasmania in the 1960s (Hickey and Wilkinson 1999a). This followed the first attempts to elucidate the fundamental requirements for successful regeneration in the natural system (Gilbert 1959; Cunningham 1960a), namely intense wildfires which remove both the litter layer, exposing receptive seedbed, and much of the canopy, increasing available light levels. Prior to the 1960s harvesting in wet forests was by 'sawmiller selection', and regeneration arose fortuitously as a consequence of deliberately or accidently lit fires (Hickey and Wilkinson 1999a). Clearfelling was extended for a time in the 1970s to dry and high altitude eucalypt forests, but following sporadic regeneration failures, successful methods for partial harvesting of these forest types were developed and are now widely implemented (Hickey and Wilkinson 1999a). Clearfelling remained the method of choice for harvesting most wet eucalypt forests however because it was safe, practical and effective in creating well-stocked regeneration, and because trials of other harvesting methods in the 1990s (Squire 1990; Campbell 1997; Neyland *et al.* 1999; Bassett *et al.* 2000) had failed to identify an alternative system to clearfelling that was safe, practical and suitable for broad application.

Clearfelling has long been perceived as damaging to forests; for example in Germany in the early 1800s, widespread clearfelling of native deciduous forests and subsequent planting with spruce, sometimes on unsuitable sites, led to conflict which culminated in the Baden Forest Law of 1833, that prohibited clearfelling (Troup 1928). In Australia, critics of clearfelling in wet eucalypt forest have argued that the regeneration is even-aged and lacks structural complexity compared to that arising following wildfires (Lindenmayer and Franklin 1997). In addition, rotations of around 90 years based on repeated clearfelling with burning and sowing are likely to lead to a decline in the abundance of late successional species and structures (Hickey 1994; Lindenmayer and McCarthy 2002). Ecologically sustainable forest management demands that timber producers move away from clearfelling and the creation of stands of even-aged regeneration, towards new silvicultural techniques that maintain more structurally complex multi-aged stands (Lindenmayer and Franklin 1997). The first challenge in the late 1990s in striving to move in this direction in tall oldgrowth wet eucalypt forests remained development of alternative harvesting methods that were safe and practical. The second challenge was to still be able to regenerate the forest with stands that have the potential to produce wood as good as that which the natural system delivers and had been achievable with CBS; this means regeneration densities at age three years that are at least in the order of 3000 stems per hectare and preferably much higher (Florence 1996; Forestry Tasmania 2003).

Vigorous debate about clearfelling has taken place in Australia virtually since the practice commenced (e.g. Routley and Routley 1973) and it has attracted a long series of Government-initiated inquiries (Elliott *et al.* 2008). The social and political pressure to achieve more ecologically-based sustainable forest management was recognised by Australian Governments, both State and Federal, and formalised in the National Forest Policy Statement (NFPS 1992). The NFPS made a commitment to more sustainable and adaptive forest management, firstly through maintaining ecological processes and the biological diversity of forests, and secondly by optimising the benefits to the community. The policy recognised that research and monitoring was central to adaptive forest management. The Warra Long-Term Ecological Research (LTER) site was established in 1995 to provide a focal point for such research (Brown *et al.* 2001). The Commonwealth and Tasmanian Governments signed the Regional Forest Agreement (RFA) in November 1997, (Commonwealth of Australia and State of Tasmania 1997). In 2005, the Tasmanian Government adopted a policy to reduce the use of clearfelling in State (public land) oldgrowth forests. This policy was subsequently recognised and supported by the Commonwealth Government in the Supplementary Tasmanian RFA, also known as the Tasmanian Community Forest Agreement (TCFA; Commonwealth of Australia and State of Tasmania, 2005). In the TCFA, there is a specific commitment to achieve non-clearfell silviculture in a minimum of 80% of the annual oldgrowth forest harvest area on State forest by 2010.

The Warra silvicultural systems trial (SST) was established within the LTER site from 1998 to 2007 (Hickey *et al.* 2006; Neyland *et al.* 2009) to compare clearfelling of tall wet eucalypt forests with alternative harvesting treatments. As the political framework changed over the establishment period, so consequently did the aims of the trial. It was originally established "to compare feasible alternative systems with the routine clearfell, burn and sow system, and to develop silvicultural alternatives for areas where habitat, special species timbers or aesthetic values have additional emphasis" (Hickey *et al.* 2001). After the signing of the TCFA, the aim was "to develop a safe, practical and broadly applicable alternative to clearfelling for use in tall wet oldgrowth forests" (Forestry Tasmania 2009b).

A necessary detail in developing a safe, practical and broadly applicable alternative to clearfelling was a definition of "clearfelling". In broad terms, gaps with a diameter less than the local average tree height are not clearfells, whereas openings of say more than ten tree heights wide are clearfells (Bradshaw 1992). Baker (1934) separated "strips" from clearfells on the basis of forest influence, strips being openings sufficiently narrow, "say less than four times the height of the mature timber… so as to have their ecological conditions greatly affected by the adjacent standing timber". The idea that adjacent forests influence the regenerating forest arises because for many tree species, the majority of the seed falls within one tree height of the parent tree (e.g. Hickey *et al.* 1982). Close proximity to retained forest presumably also influences the regenerating forest with regard to many other elements of the biota, although there has been little actual research to develop the detail (Tabor *et al.* 2007; Rosenvald and Lõhmus 2008). The concept of forest influence has been formally defined as "the biophysical effects of forests or individual trees on the environment of the surrounding land" (Mitchell and Beese 2002).

While the Warra SST was being established, the same social and political pressures were being felt around the world, and in many countries where clearfelling was used trials were established to explore alternatives (e.g. Squire 1990; Larsen 1995; Scientific Panel for Sustainable Forest Practices in Clayoquot Sound 1995; Arnott and Beese 1997; Franklin *et al.* 1997; Fries *et al.* 1997). Franklin *et al.* (1997), in describing the variable retention harvest systems used in the Pacific Northwest, referred to aggregated retention, dispersed retention, and combinations thereof; Franklin *et al.*'s terminology was subsequently widely adopted internationally, including in Tasmania. These authors listed three main objectives of variable retention harvesting:

- 'lifeboating' of species and processes into the regenerating stand;
- enriching the regenerating stand with structural features that would be absent following traditional CBS operations; and
- enhancing connectivity in the managed landscape.

Franklin *et al.* (1997) acknowledge particularly that retaining structural diversity into the regenerating stand will have consequent benefits for compositional diversity. One of the stated aims of variable retention harvesting is to maintain forest influence over the majority of the harvested area (Beese *et al.* 2003). This aim has been adopted in Tasmania, and has become the key measure by which variable retention harvesting is distinguished from clearfelling (Forestry Tasmania 2009b).

The Warra silvicultural systems trial (SST)

The original plan for the Warra trial comprised four treatments:

- clearfell, burn and sow with dispersed understorey islands that occupy <5% of the coupe area;
- stripfells, 80-m wide, and a wider patchfell, implemented to explore likely dispersal distances for eucalypt seed;
- dispersed retention, with about 10% by basal area of the original forest retained as evenly dispersed trees; and
- single tree/small group selection with openings up to 45 m in diameter.

Following a review of the trial in 2000 the aggregated retention treatment was added. In this treatment about 30% by basal area of the original forest was retained as evenly dispersed groups of trees. Safety issues that arose during and after the first implementation of the single tree/small group selection treatment led to revision of this treatment; the minimum opening was increased to two tree heights or 80 m.

In developing these treatments, three major constraints were recognised (Hickey *et al.* 2001):

- the fuels loads following harvesting in wet eucalypt forests are very high (Frankcombe 1966; Marsden-Smedley and Slijepcevic 2001), so site preparation treatments must be able to reduce or remove this fuel;
- the treatment must be able to produce adequately stocked and vigorously growing regeneration of the eucalypts; and
- the system must be operationally feasible with regard to safety, productivity and economic viability.

Evaluation of the Warra trial encompasses four main criteria: social, economic, ecological and silvicultural (Hickey *et al.* 2006). The focus of this study was on the ecological and silvicultural outcomes of the treatments.

The Warra SST was not established as a fully replicated randomised block design. To do so, with three different vegetation types, six different silvicultural systems and the necessary replication to enable full statistical analyses of the responses was beyond the available resources. The protracted establishment period meant there was uncertainty about the effects of seasonal variation on the outcomes. The analyses that could be completed with the available data set were consequently restricted, but remain informative.

The floristic response

The floristic response of disturbed quadrats in harvested areas in the first three to six years following the harvesting and burning disturbance was related to the pre-harvesting floristics and not to the silvicultural system. This is because there are few levels of disturbance when harvesting wet eucalypt forest. The size of the trees, the density of the understorey and the need for manoeuvrability of machinery mean that wherever there has been harvesting, the standing forest is reduced to a layer of crushed vegetation. After burning or mechanical heaping of the debris, the ground conditions are very similar and independent of the silvicultural system being applied to the coupe.

Sclerophyll dominated understoreys regenerated with a very similar species composition to that pre-harvesting, and in time will presumably recover a similar structure. The pattern of recovery of the sclerophyllous understoreys at Warra was similar to that observed in regenerating sclerophyllous understoreys in wet eucalypt forests elsewhere in Australia (Cremer and Mount 1965; Cook and Drinnan 1984; Mueck and Peacock 1992; Ough and Ross 1992; Peacock 1994; Chesterfield 1996).

Rainforest dominated understoreys regenerated with a very different species composition to that pre-harvesting. The post-harvest vegetation was dominated by a suite of sclerophyllous species and is very similar in species composition and structure to that on areas that carried sclerophyll-dominated understoreys pre-disturbance. A similar response has been observed in rainforest disturbed by fire (Barker 1991). While the rainforest tree species, for example myrtle, blackwood, leatherwood, celery-top pine and sassafras, were all present in the post-harvesting vegetation, they were much less abundant than prior to the disturbance. The shrubs, orchids and epiphytic ferns were not present in the post-harvesting vegetation by age six years. Hickey (1994) examined 20- to 30-year-old silvicultural regeneration compared to wildfire regeneration and found that the epiphytic ferns were still less common in the silvicultural regeneration than in the wildfire regeneration, so these species in particular take some years to return to their pre-disturbance abundance. It remains unclear as to how many years will be required for other species to return to their pre-harvest condition.

At the coupe level the floristic response varied according to the treatment. Even the understorey islands, whose small size meant they were vulnerable to windthrow where exposed to prevailing winds and difficult to protect during the regeneration burns, contributed some structural and floristic elements to the regenerating stand. The rainforest species, for example leatherwood and sassafras, that survived within the islands during the regeneration burn, have not only persisted within the regenerating stand but will have the opportunity in the future to contribute seeds to accelerate their broader recovery within the surrounding regenerating forests. In all the other treatments except dispersed retention, the significant areas retained within the coupes have carried the pre-harvesting vegetation, predominantly undisturbed, into the regenerating stand.

Understorey island and aggregate size

The key lesson from the understorey islands was that unharvested areas for in-coupe retention needed to be larger in size than the 0.08 ha used in this treatment. This finding informed the harvesting prescription for, and retention of, aggregates of one quarter to one hectare in the aggregated retention treatments. The larger of these aggregates, and the retained belts in the stripfell treatments, remained largely intact throughout the disturbances with burn and windthrow damage affecting less than 10% of the retained area overall. However, the smaller and/or more exposed aggregates again proved to be the most vulnerable to windthrow and/or burning damage. This suggests that aggregates should be even larger than used in the experiment. The current operational recommendation is that aggregates should be in the order of one to three hectares; aggregates may be islands or retained on the edges of harvested areas, as edge aggregates are considered more resistant to disturbance than islands (Forestry Tasmania 2009a). Retaining larger aggregates should ensure that they are not only able to serve the desired lifeboat function, but also that they are more able to serve as sources of propagules to the adjacent regenerating stand. Larger aggregates will also provide planners in the future with more harvesting options; for example in a future harvest part of the original aggregate could be retained along with some of the now *circa* 90-year-old regeneration, creating a stand with a greater diversity of forest age classes and improved biodiversity outcomes. The other part of the original aggregate could be harvested to provide specialist products only available from older trees. Given aggregates of sufficient size, this pattern could be repeated indefinitely into the future (see Figures 8.1 to 8.4). The larger the area retained in the original aggregates, the greater the future flexibility. The figures illustrate the importance of retaining aggregates not just for one rotation, but into successive rotations as well.

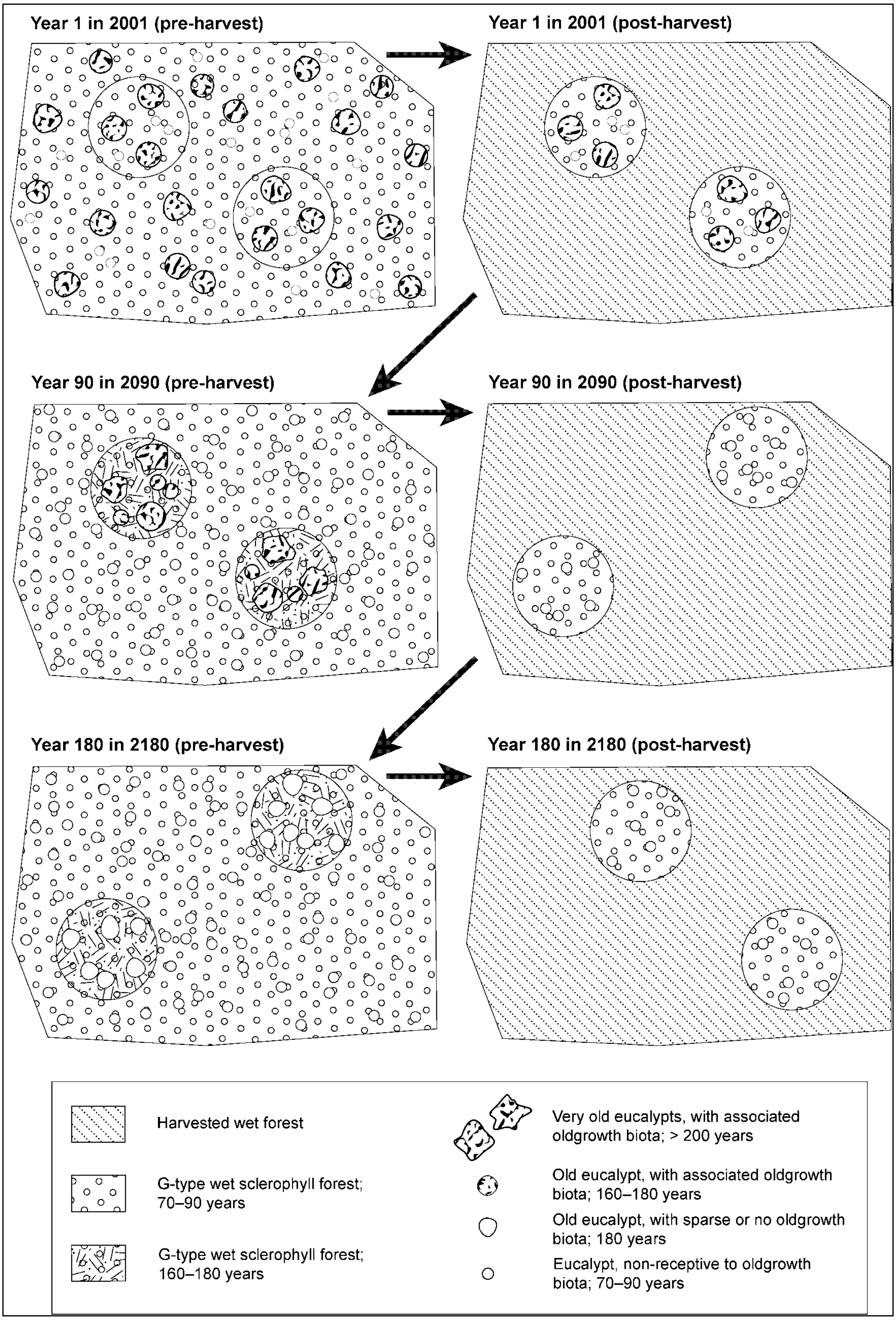


Figure 8.1. A stylised coupe comprising G-type *Eucalyptus obliqua* forest, with sclerophyll dominated understoreys. At each harvest, previously established aggregates are felled, and new aggregates are retained. Note that with this pattern, the oldest elements ever present, the oldgrowth trees and their associated biota retained within aggregates at the first harvest, are lost in the second harvest. Subsequently, there will be nothing older than 90 years, although the vegetation will retain its G-type character.

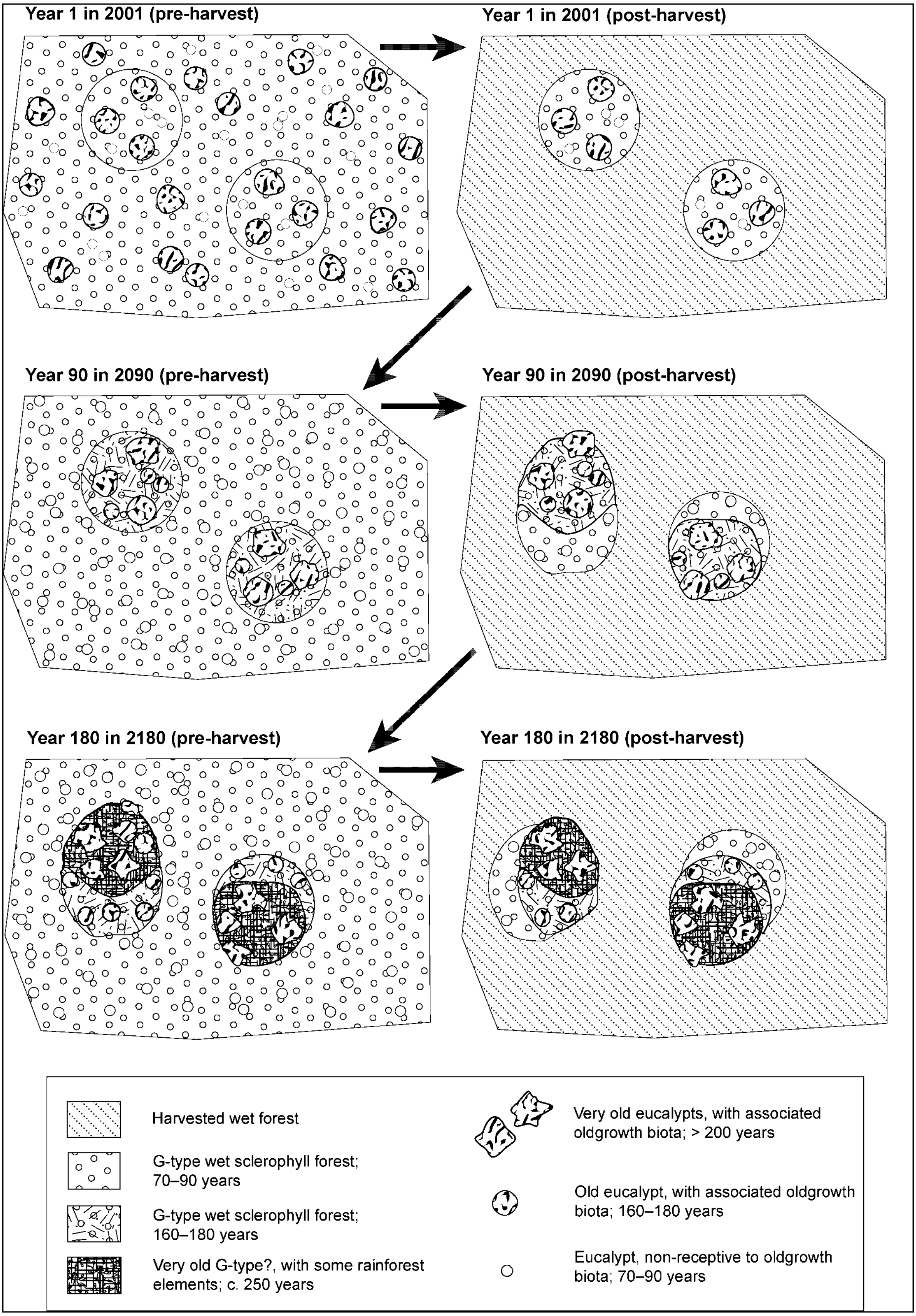


Figure 8.2. A stylised coupe comprising G-type *Eucalyptus obliqua* forest. At each harvest, most of the previously established aggregates are kept although a small portion may be harvested, and some new areas are retained. In this pattern, assuming no wildfires, the retained oldgrowth elements persist, and new oldgrowth elements can develop. The vegetation retains its G-type character but with improved biodiversity outcomes compared to the pattern in Figure 8.1.

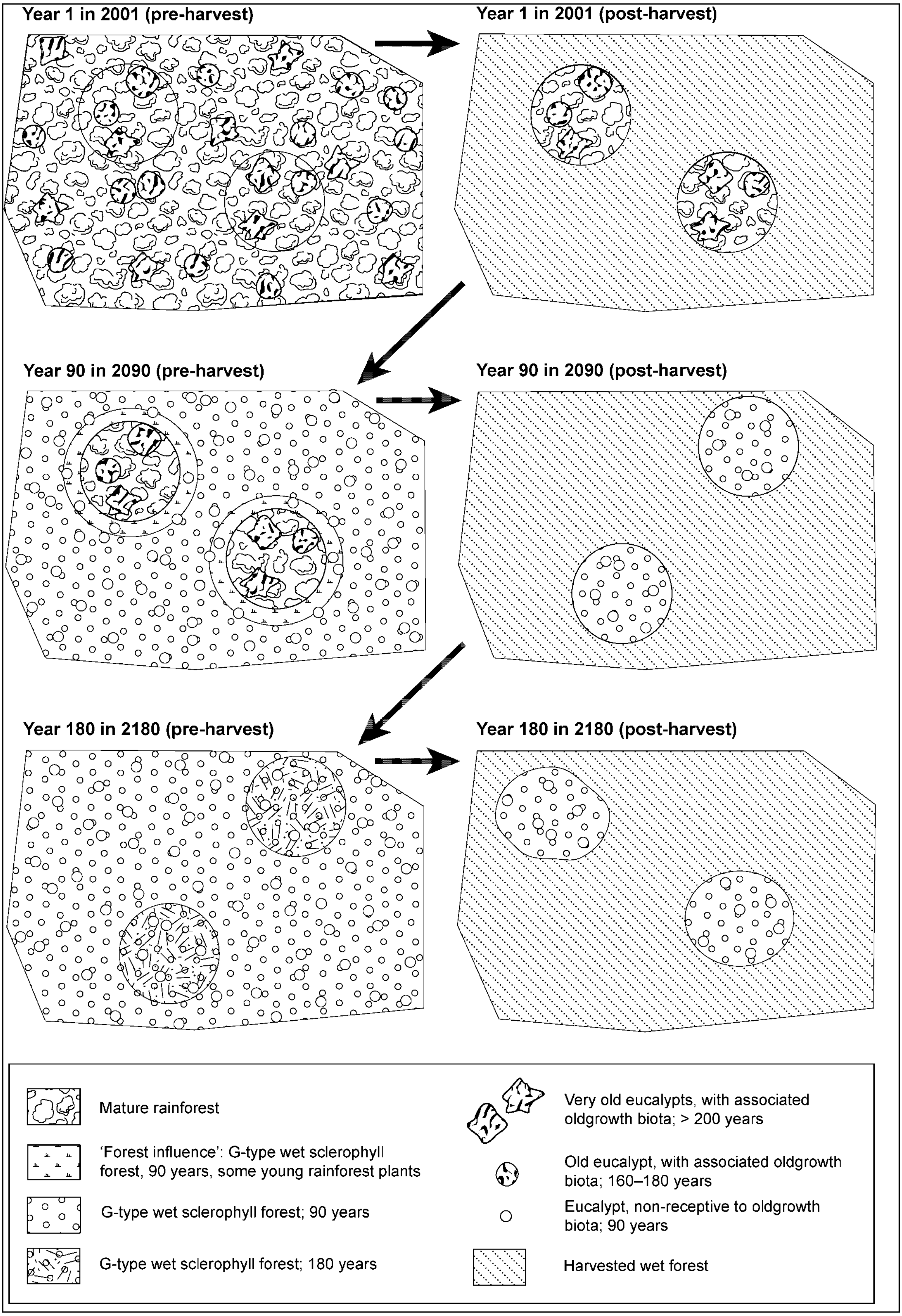


Figure 8.3. A stylised coupe comprising C-type *Eucalyptus obliqua* forest, with rainforest dominated understoreys. At each harvest, previously established aggregates are felled, and new aggregates are retained. As in Figure 8.1, the oldgrowth elements are lost from the harvested area in the second harvest. In addition, the nature of the understorey changes from rainforest to sclerophyll forest.

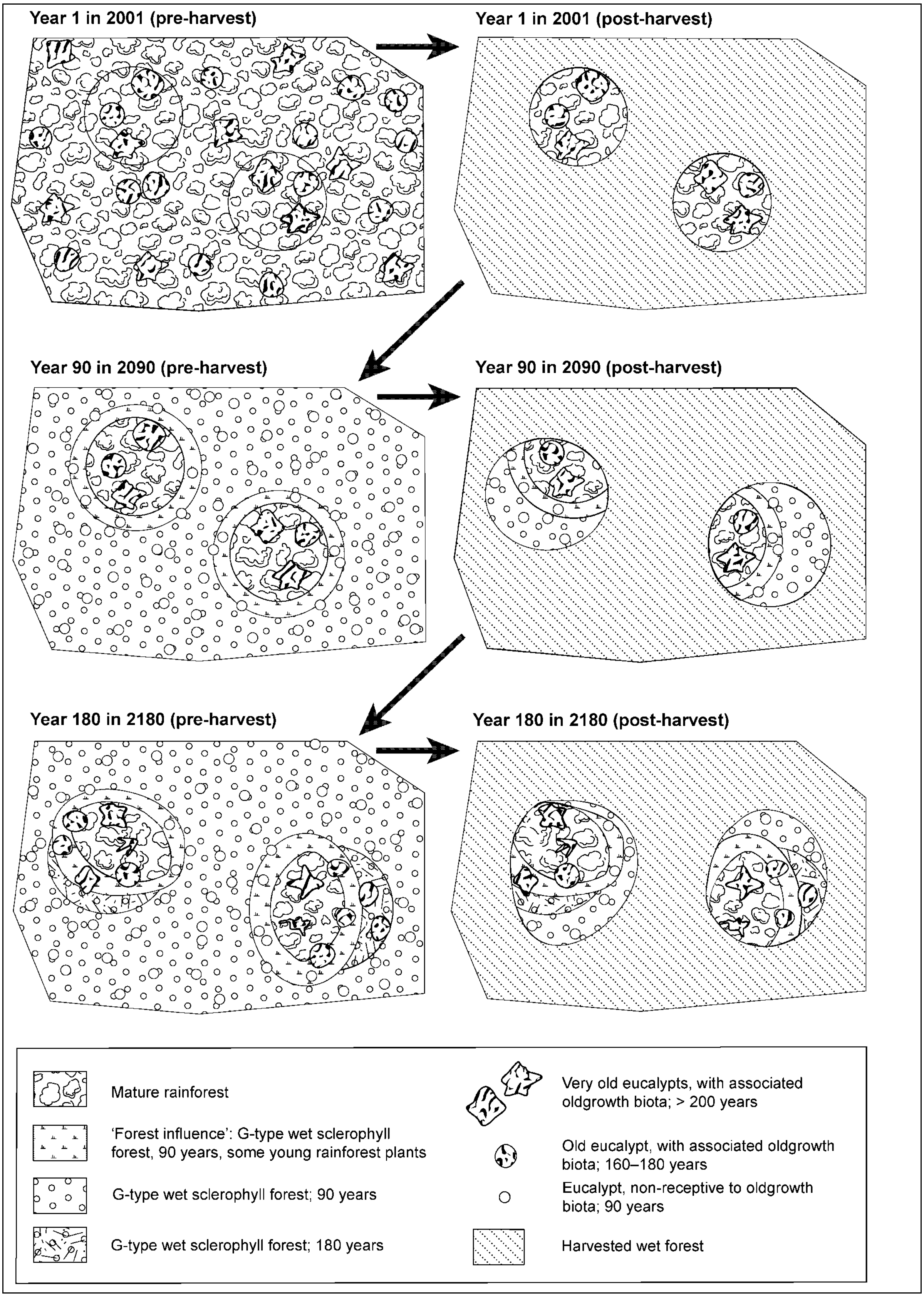


Figure 8.4. A stylised coupe comprising C-type *Eucalyptus obliqua* forest, with rainforest dominated understoreys. At each harvest, most of the previously established aggregates are kept although a small portion may be harvested, and some new areas are retained. In this pattern as in Figure 8.2, assuming no wildfires, the retained oldgrowth elements persist including patches of the original rainforest understorey, and although much of the coupe is converted to G-type wet sclerophyll forest, new oldgrowth elements can develop over time.

Seedling regeneration

The abundance and growth rates of the eucalypt regeneration were strongly related to the nature of the seedbed. The highest eucalypt seedling densities and fastest early growth rates occurred on the hottest burnt seedbeds. The lowest seedling densities occurred on unburnt and undisturbed seedbeds and the slowest early growth rates occurred on unburnt and compacted seedbeds. The nature of the seedbed in each coupe was related to the harvesting and regeneration treatment. Where high intensity burns were applied there was a higher proportion of burnt seedbed available than in coupes where low intensity burns were applied. Treatments that created the most burnt seedbed had the highest eucalypt seedling densities and mean seedling growth rates.

Eucalypt seedling density is also influenced by the amount of seed that is applied to the coupe, either artificially or naturally. All else being equal higher sowing rates are likely to lead to higher early seedling densities. For example, the standing seed crop in the first dispersed retention coupe was much greater than in the second, and by age three years the seedling density in the first coupe was nearly three times that in the second. One of the advantages of silvicultural systems that retain trees within the harvested areas is the potential for ongoing seedfall; this is commonly exploited in partial harvesting systems in high altitude and dry eucalypt forest in Tasmania (Forestry Tasmania 2001; Forestry Tasmania 2002b). Seed crops are not always present in eucalypts, but when they are and there is ongoing seed fall then this can contribute to the final stand density (*op. cit.*). This effect is apparent in photo 2.6, where the part of the harvested area that is close to the retained forest and immediately windward of it is well stocked with eucalypts, whereas the part further east is poorly stocked where seedfall was limiting. An early decision was made not to oversow the coupes in the SST. As this was a research trial it was acknowledged that this decision may have resulted in a lower than desirable stocking but there was research interest in assessing the potential of the treatments to achieve adequate stocking by natural means.

Safety, coupe size and the economics of harvesting

The dispersed retention and single tree/small group selection treatments were found to be too dangerous for routine operational use for tall wet eucalypt forests. Such systems in this trial and elsewhere led to a significant increase in exposure to overhead hazards, and an increased risk of felled trees striking standing trees (Mitchell 1993; Bloch and Murphy 1994; Neyland *et al.* 2009). Group selection, patch-felling, and strip-felling using openings at least two-tree heights wide, which reduces exposure to overhead hazards and in which the openings are large enough to fell trees safely, may have application in specific circumstances. For example, in Tasmania some areas of mixed forest are set aside with a priority for producing special timbers on a longer rotation than is typically applied in more intensively managed eucalypt production areas. However, reducing the mean coupe size has a significant impact on the economics of the operation (Nyvold 2001). For the same level of wood production, halving the average coupe size doubles the number of openings and regeneration burns required, reduces the tonnes of wood produced per kilometre of road constructed and increases the planning and supervision requirements (Campbell 1997). These systems are therefore not suitable for broader application as alternatives to clearfelling.

One of the consequences of the decision to adopt the internationally accepted terminology for variable retention is that clearfell, burn and sow with understorey islands would rarely and could not in practice meet the "forest influence over the majority of the harvested area" target. Consequently, this system, while it created excellent eucalypt regeneration, presented no safety or operational issues, and had some biodiversity gains compared to routine clearfell operations, is also not considered suitable for broader application as an alternative to clearfelling.

Aggregated retention

No safety or operational issues were reported in the harvesting and burning of the aggregated retention coupes. Three years after completion of the harvesting and regeneration treatments, the aggregated retention coupes retained significant structural and biological legacies from the pre-harvest stand into the post-harvest stand. The stocking of the regeneration at age three years in both the aggregated retention coupes in this trial reached the minimum required level but was below the level considered necessary for future intensive forest management and maximum wood production (Florence 1996; Forestry Tasmania 2003). Of the alternatives to clearfelling examined in this study, aggregated retention is currently considered the most suitable alternative to clearfelling for harvesting of tall wet eucalypt forest in Tasmania, and is already being applied operationally (Hickey *et al.* 2006).

An independent review of the first 21 operational aggregated retention coupes found that the hazards associated with their harvesting were the same as those known to exist in clearfell harvesting (Howard 2008). The higher perimeter-to-area ratio in aggregated retention means that there is an increased risk due to a greater proportion of the contractor's time being spent proximate to an edge. As awareness, identification and risk avoidance of hazardous trees is part of any operation, managing this risk should present no issues for harvesting contractors. This is a very important finding in the development of alternatives to clearfelling. Timber harvesting is dangerous enough and it is essential that the safety hazard posed by alternatives to clearfelling is not significantly greater than that posed by clearfelling (Forestry Tasmania 2009b).

Trade-offs

Traditional high intensity burns that have been successfully applied for many years to clearfelled wet eucalypt forests (Marsden-Smedley and Slijepcevic 2001), cannot be conducted in coupes with retained aggregates (Chuter 2007), as this would most likely result in the aggregates being burnt or at least heavily scorched during the burn, an outcome that will compromise their value as 'lifeboats'. As noted above, this experiment has clearly demonstrated that the eucalypt seedling regeneration is compromised by cooler burns. Cooler burns have two consequences. Firstly the "ashbed effect" that results in high nutrient availability to the developing eucalypt regeneration (Pryor 1960) is muted resulting in more slowly-growing regeneration; secondly there is a lower proportion of burnt seedbed in such coupes resulting in sparser regeneration. Consequently, the longer term productivity of the eucalypt regeneration may be reduced compared to traditionally clearfelled and high intensity burnt coupes. To minimise these potentially undesirable outcomes, Chuter (2007) has recommended that the ideal conditions under which to conduct burns in aggregated retention coupes are those associated with very dry fuels in the harvested areas and damp fuels in the adjacent forest, which can be achieved when settled autumn days follow a period of rain, and with stable weather systems and light winds. Under such conditions the harvesting debris can be lit sparsely, late in the day when the relative humidity is rising, and the fire will spread slowly without creating a strong convection column. The fire will consume the majority of the fine fuels, creating receptive seedbed, and scorch to the retained aggregates should be kept to a minimum.

The need to establish vigorous natural regeneration quickly and abundantly following the regeneration burn is particularly important in wet eucalypt forests. In dry eucalypt forests regeneration can occur over a much longer time frame (Pennington *et al.* 2001b). In the Pacific Northwest and in Europe, planting of seedlings of preferred species is commonly used to enhance natural regeneration (e.g. (D'Anjou 2001; Karlsson and Nilsson 2005; Watts and Tolland 2005; Mitchell *et al.* 2007), and in South America and New Zealand natural *Nothofagus* regeneration is usually abundant and establishes successfully without fire (Lara and Donoso 2000; Stewart *et al.* 2000; Gea-Izquierdo *et al.* 2004,).

Ecological silviculture v. production forestry

Future monitoring of the biodiversity outcomes in aggregated retention coupes is essential. One of the key roles of retained aggregates is as lifeboats (Franklin *et al.* 1997) to carry elements of the pre-harvest stand into the post-harvest stand; a second role is to act as a source of propagules to accelerate the rate of recovery of species diversity in the regenerating stand, i.e. providing forest influence over the regenerating stand. There is some evidence for the first of these roles in wet eucalypt forests: the retained aggregates in the first 21 operational coupes have remained relatively undisturbed through the course of harvesting and the retained oldgrowth elements within these aggregates have therefore been carried successfully into the regenerating stand (Baker *et al.* 2009; Forestry Tasmania 2009b). However evidence for aggregates acting as a source of propagules is poor. Tabor (2007) has shown that rainforest species regeneration is greater close to mixed forest edges, but there is little other hard evidence to corroborate this finding in the Australian literature. Rosenvald and Lõhmus (2008) reviewed 214 North American and European studies; they also found extensive evidence to support the value of retention for lifeboating species and habitat values into the regenerating stand, but very little evidence for their value in providing influence. This may be partly due to the duration of the studies, most of which were short-term, and partly because variable retention harvesting is a recent phenomenon. There is some scope for using previously created forest edges as surrogates to determine the effects of forest edges in older regenerating stands, as done by Tabor *et al.* (2007), but this may not reflect the influence provided by island aggregates. Biodiversity monitoring in operational aggregated retention coupes has commenced (e.g. Garandel *et al.* 2009) but as the oldest coupes are just five years old, this work is in its infancy.

The quality and quantity of the young eucalypt regeneration in operational aggregated retention coupes must also be monitored. Early monitoring to age three years of these coupes (Robyn Scott, pers comm.) indicates that the eucalypt seedling density in the 2007 operational aggregated retention and comparable clearfell, burn and sow coupes was 1500 and 2700 stems per hectare, respectively, at age one year. This significantly lower level of stocking in the aggregated retention coupes is insufficient to foster the important early competition that selects for the most vigorous seedlings and develops stands of strong healthy regrowth (Jacobs 1955; Florence 1996). If the stands are inadequately stocked at age three years, this absence of early and intense competition can also result in trees of poor form and with a higher incidence of decay (Wardlaw 2003). Therefore it is also important that the quality and quantity eucalypt regrowth be monitored over at least the first 15 to 25 years, in order to follow the stand development processes until the final crop trees have developed.

There is some evidence to suggest that regeneration within up to 10 m of the edges of harvested areas does not grow as well as that further away from edges (Florence 1996; Wang *et al.* 2008). In aggregated retention coupes a greater proportion of the coupe is close to an edge than if the same coupe were clearfelled. As the regeneration in aggregated retention coupes is not expected to be as abundant or as vigorous as in comparable clearfell coupes due to the lower intensity regeneration burn, further reduction of the coupe productivity because of edge effects could be a cause for concern.

Remote sensing methods, particularly LiDAR, have the potential to allow rapid assessment of such effects.

The social licence

Developing an alternative harvesting method to clearfelling for use in wet eucalypt forests that meets both ecological and silvicultural goals achieves little if the method does not find broad social acceptance. The current social acceptability in Australia of clearfelling of wet eucalypt forests, and particularly of oldgrowth wet eucalypt forests is low (Forestry Tasmania 2009b). Research on social acceptability has shown that, on visual appearance alone, most people interviewed rate clearfelling as the least acceptable method of harvesting native forests and selective logging as the most preferable. With the benefit of additional information about the harvesting systems, variable retention is ranked with selective logging (Ford, in press 2009; Ford *et al.* submitted 2009).

An international perspective

Variable retention is being adopted widely as an alternative to clearfelling in wet temperate forests e.g. the Pacific Northwest of the U.S.A., (Franklin *et al.* 1997), Europe, (Fries *et al.* 1997; Vanha-Majamaa and Jalonen 2001) Canada, (Beese *et al.* 2003), South America (Martinez Pastur *et al.* 2007) and elsewhere in Australia (Lindenmayer 2007)), to increase the level of structural retention, to retain identified stand attributes of particular biological importance, and to ensure that these attributes are as evenly distributed as possible for at least the duration of the rotation (Franklin *et al.* 1997; Lindenmayer 2007; Scott 2007). A fundamental premise of variable retention is that it is more ecologically valuable to distribute older forest elements throughout the production forest landscape rather than to simply add an equivalent amount of older forest to the large, existing reserve system. Variable retention coupes are also expected to improve ecological outcomes in the longer term, to provide flexibility for subsequent land-use decisions and to retain a social licence to continue to produce timber from natural and semi-natural forests (Hickey *et al.* 2006).

Ongoing research into the ecological and silvicultural benefits of aggregated retention is essential in order to more clearly understand the costs and benefits of adopting this method in preference to clearfelling. Research into the social acceptability of the method is also important, as are efforts to improve public understanding of the rationale behind the method, as public views change with better understanding.

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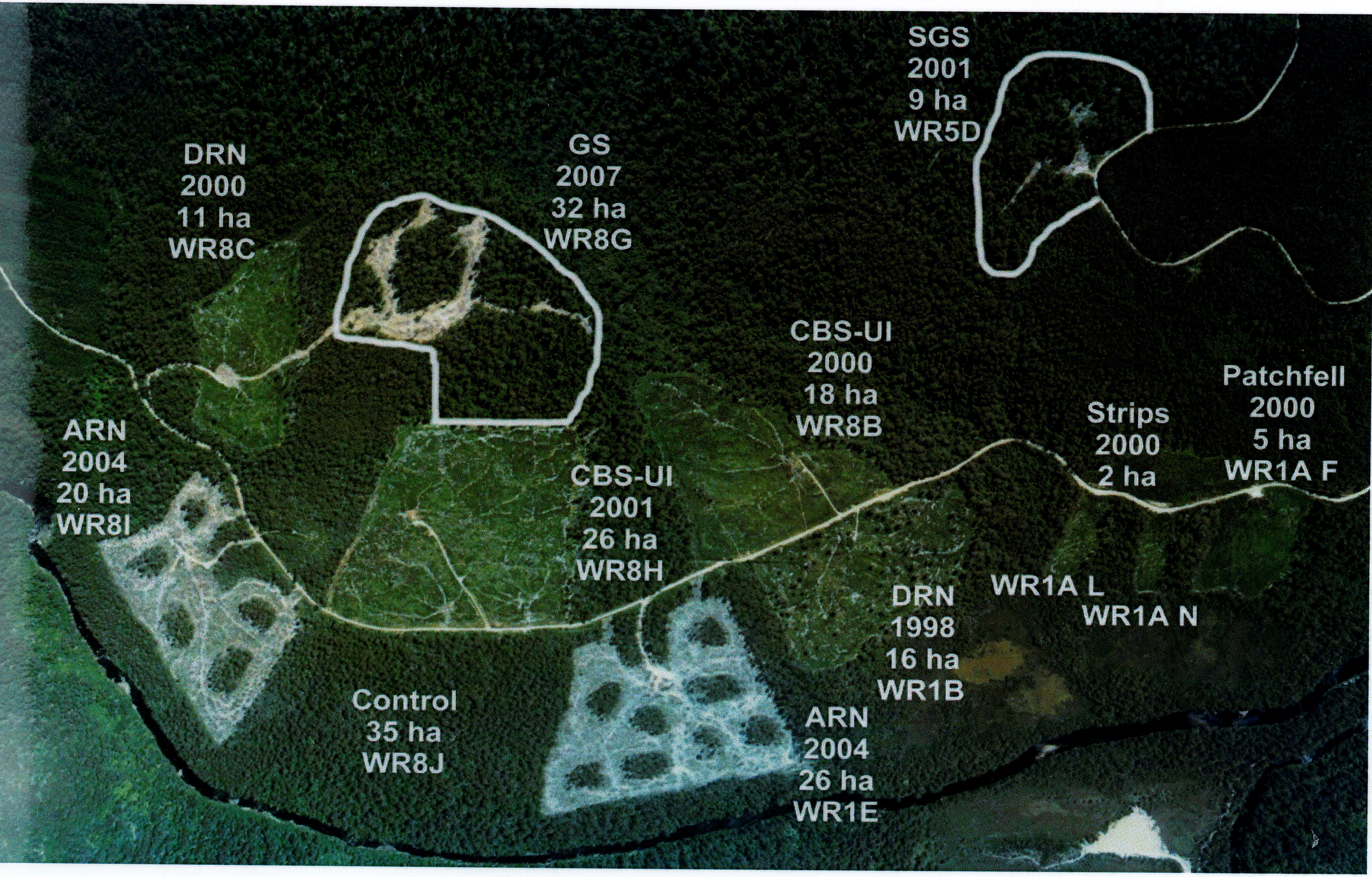
Treatments at the Warra Silvicultural Systems Trial as at May 2010

Treatment	*Potential benefits*	*Coupe name*	*Logged - burnt*	*Regeneration @ 3yo spha @ cm tall*
Clearfell, burn and sow (CB&S)	routine system	8B 8H	1998 2000 2000 2001	4410 @ 205 9960 @ 192
CB&S with understorey islands (40 m by 20 m machinery-free areas)	>biodiversity retention	8B 8H	1998 2000 2000 2001	4410 @ 205 9960 @ 192
Stripfell (Cable) (80 m strips; natural seedfall)	>mixed forest regeneration >on-site seed <soil damage	1A (N) 1A (L)	1999 2000 1999 2000	3750 @ 230 2700 @ 216
Patchfell (Cable) (240 m wide; natural seedfall)	<soil damage estimate max. strip width	1A (F)	1999 2000	1760 @ 217
Dispersed Retention (10-15% BA retention, low intensity burn; natural seedfall)	>habitat retention >soil organic matter >landscape >biodiversity retention >large log supply	1B 8C	1998 1998 1999 2000	2860 @ 104 1200 @ 112
Aggregated Retention (30% area retention, majority of harvest within 1 tree length of retained forest, retain aggregates of 0.5 to 1.0 ha; low intensity burn, natural seedfall)	>landscape >worker safety >habitat retention >soil organic matter >biodiversity retention >large log supply	8I 1E	2003 2004 2003 2004	1720 @ 141 1260 @ 140
Single tree/ small group selection (permanent snig track, harvest 40 $m^3 ha^{-1}$ every 20 years, scarification or burning, natural seedfall)	>biodiversity retention >habitat retention >soil organic matter >advanced growth retention >special timbers supply	5D 8G	2001 no burn 2006 2007	940 @ 45 1067 @ 51
Control (no harvest or regeneration treatment)	study long term change	8J 8K	No treatment	


SGS
2001
9 ha
WR5D
DRN
2000
11 ha
WR8C
GS
2007
32 ha
WR8G
CBS-UI
2000
18 ha
WR8B
Patchfell
2000
5 ha
WR1A F
Strips
2000
2 ha
ARN
2004
20 ha
WR8I
CBS-UI
2001
26 ha
WR8H
WR1A L
WR1A N
DRN
1998
16 ha
WR1B
Control
35 ha
WR8J
ARN
2004
26 ha
WR1E